THE

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OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant. —*Novum Organum, Præfatio.*

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THE

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1. *On our* Present Knowledge *of the* Invertebrate Fauna *of the* Lower Carboniferous *or* Calciferous Sandstone Series *of the* Edinburgh Neighbourhood, *especially of that Division known as the* Wardie Shales; *and on the* First Appearance *of certain* Species *in these Beds.* By R. Etheridge, Jun., Esq., F.G.S. (Read November 7, 1877.)

[Plates I. & II.]

Introduction.—Little or no attention has been paid to the organic remains of the great series of strata below the Gilmerton or No. 1 Limestone of the Midlothian coal-field (adopted as the conventional base of the Carboniferous Limestone series by the Geological Survey), when compared with the numerous papers and other publications bearing on the fossils of the overlying strata or *Carboniferous Limestone Series.* It is true the fishes were examined by Agassiz *, and the plants to some extent by Lindley and Hutton, but in both cases only to a limited extent. Dr. Hibbert's celebrated paper on the Burdiehouse Limestone appears to have been the first memoir in which any systematic observations were recorded; and, with the exception of a few miscellaneous publications in the interim, it was not until the Geological Survey broke ground in the Edinburgh neighbourhood that any further detailed work of this nature was under-

* The study of the Fishes has been resumed by Dr. Traquair, F.G.S.

taken. We have the result of Mr. Salter's examination of a collection of fossils made by Messrs. R. Gibbs and W. Rhind during Prof. Geikie's survey of the district, in the Appendix to the 'Geology of the Neighbourhood of Edinburgh.' Notwithstanding that Mr. Salter's observations were confined to a mere list of the species obtained by the collectors, there can be no doubt that his were the first systematically carried out, and that they laid the foundation for future research.

In this communication I propose to give:—first, a summary of our present knowledge of the Invertebrate Fauna of the Calciferous Sandstone series as developed in the Edinburgh neighbourhood; secondly, a description of the fossils from a particular horizon in the series, the Wardie Shales, contained in the cabinets of Mr. John Henderson and Mr. Gall; and, thirdly, some general remarks on the first appearance of certain species in the Calciferous Sandstone series of this district. It will not be out of place, perhaps, for me to give a few particulars as to the extent and subdivisions of the Calciferous Sandstone Series before proceeding to the first of the foregoing subjects.

The strata comprised in the Calciferous Sandstone or Lower Carboniferous Series of Edinburghshire, as elsewhere in Scotland, speaking generally, are divisible into a superior or Cement-stone group and an inferior or Red Sandstone group. The former consists in this district of sandstone, shales, oil-shales, some thin corals, and a few limestones; the latter of red and grey sandstones, conglomerates, marls, and cornstones *. Speaking of these divisions in the district in question, Prof. A. Geikie says the lower group "forms the ground on which the greater part of Edinburgh is built, whence it stretches southward by Craigmillar to Liberton, and south-westward along the western flank of the Pentland Hills. . . . . . The various strata [of the upper group] extend from the western and northern part of Edinburgh westward to Linlithgow, and south-westward by the Cobinshaw Reservoir into Lanarkshire" †.

The lower, or Red Sandstone group, has proved so unfossiliferous, hitherto, that it may be dismissed for the present. Passing to the Cement-stone group, the first well-marked horizon we meet with is formed by a "series of sandstones, shales, and thin limestones" in the streams flowing into the Clubbidean Reservoir from the northern flank of the Pentland Hills ‡. Above this there appear to be several well-marked horizons; but as regards their order of superposition and relation to one another, there is some diversity of opinion. According to Prof. Geikie, the next most important group is that of the Wardie Shales exposed along the course of the Water of Leith, traceable for about six or seven miles southwards from their exposure on the shore of the Firth of Forth, at Newhaven or Wardie between Leith and Granton, and overlain by a vast series of

* J. Geikie, 'The Carboniferous Formation of Scotland,' p. 9.

† Descriptive Cat. Rock Specimens Geol. Survey Scotland, p. 18; see also Mem. Geol. Survey Scotland, 1861, No. 32, pp. 16–42.

‡ A. Geikie, Memoir 32, p. 18.

yellow and white thick-bedded sandstones, the Granton and Craigleith Sandstones *. On the other hand, Mr. Henderson, in a recently published paper "On the Wardie and Granton Series of Sandstones and Shales" †, combats this view, and considers that the sandstones of Craigleith and Granton really underlie the Wardie Shales and form the base of the latter. In the course of his examination of the district, Mr. Henderson has observed at several localities well-marked bands of shale containing marine fossils, as at Woodhall, Dean Bridge, Drumsheugh, Craigleith, and Granton; and from the close identity of the species at these several localities he is led to consider the beds there exposed as occupying much the same position, near the base of the Wardie Shales and above the sandstones of Craigleith and Granton. Omitting all mention of contemporaneous igneous rocks, we come in ascending order to the horizon of the well-known and valuable Burdiehouse Limestone; but as this is without the scope of the present paper, it need not be further referred to here.

I. *On our present Knowledge of the Invertebrate Fauna of the Lower Carboniferous or Calciferous Sandstone Series of the Edinburgh Neighbourhood.*

So far as I have been able to ascertain, representatives of the Foraminifera, Spongida, Cœlenterata, and Echinodermata have not been recorded from the above rocks. The most likely locality to yield members of either of these divisions will be the bed of marine shale at Woodhall, in the water of Leith, afterwards to be more fully noticed.

Annelida.—In Dr. Hibbert's memoir "On the Freshwater Limestone of Burdiehouse, &c." ‡, published in 1836, the occurrence is mentioned, in the fourth section of the paper ("The Microscopic Animals contained in the Limestone of Burdiehouse"), of minute shells with "a sort of spiral organization, by no means unlike that of the *Planorbis* or *Spirorbis*." He here clearly refers to the little Annelid named about this time *Microconchus carbonarius* by Murchison. Hibbert also noticed and figured a little body which he compared to a *Nautilus*, but remarked its want of septa §. The figure

* Mem. Geol. Surv. Scotl. p. 31.

† Trans. Edinb. Geol. Soc. 1877, iii. pt. 1, p. 24.

‡ Trans. R. Soc. Edinburgh, xiii. p. 169.

§ *Loc. cit.* p. 181. I consider this little body to be a well-marked variety of *Spirorbis carbonarius*, Murchison, and offer the following description of it:—

SPIRORBIS CARBONARIUS, Murch., var. *Hibberti*, var. nov. Pl. I. fig. 2.

Nautilus, Hibbert, Trans. R. Soc. Edinb. 1836, xiii. p. 151; Rhind, Excursions around Edinb. 1836, p. 35, fig. 14 *c*.

Var. char. Size exceeding that of the species itself, the last turn of the tube increasing more rapidly; aperture with a sigmoidal or nautiliform margin reflected somewhat back over the umbilicus, which is deep. By following the direction of the surface-striæ the sigmoidal margin can be traced.

Horizon. Beds in connexion with the Burdiehouse Limestone, in the neighbourhood of Edinburgh.

of this variety of *Spirorbis carbonarius* was again reproduced by Dr. W. Rhind in a little work entitled 'Excursions illustrative of the Geology and Natural History of the Environs of Edinburgh'*. The first collective account of the Lower-Carboniferous fossils, as previously stated, was that given by Mr. Salter in the Appendix to the Memoir on the Geology of Edinburgh. The list of Invertebrata comprised exactly one dozen species, of which two were Annelids, viz. *Spirorbis carbonarius*, Murch., and *Sp. helicteres*, Salter, both obtained by Mr. R. Gibbs in the Clubbidean Limestone, at the extreme base, according to Prof. Geikie, of the Cement-stone group. *Sp. helicteres* was originally described by Mr. Salter from specimens obtained by the Rev. T. Brown, M.A., near Fifeness, and figured and described in the latter gentleman's paper "On the Mountain Limestone and Lower Carboniferous Rocks of the Fifeshire Coast"†.

Mr. Salter remarked on the unattached habit of this worm, and stated that it occurs in distinct beds, hundreds grouped together, yet without ostensible attachment to any other object than its own species. The same remark will apply to its condition at Clubbidean. In May 1870 Mr. C. W. Peach communicated a paper to the Edinburgh Geological Society "On the Discovery of *Spirorbis carbonarius* (Murchison) in the Limestone of Burdiehouse, &c."‡. The same species was again found by Mr. J. Henderson on striated stems, like Calamites, from a black shale in Forrest Road, Edinburgh§.

In a short article entitled "Palæontological Notes," contributed to the 'Geological Magazine' in July last (1877), I called attention to a *Spirorbis* occurring in a band of limestone at the Oakbank Oil Works, near Mid Calder, which appears to be closely allied to *S. siluricus*, Eichw.

Crustacea.—We are again indebted to Dr. Hibbert for the first notice of Ostracoda from this series of rocks. He named and figured *Cypris scoto-burdigalensis* and *Daphnoidea*, sp., from the Burdiehouse Limestone ‖. The first of these has since been placed in the genus *Leperditia* by Prof. T. Rupert Jones, F.R.S.; and the second has been named by him *D. Hibberti*. Dr. William Rhind also reproduced the original figures of these species ¶; and Mr. Salter recorded further localities where they might be obtained**. A very interesting paper was published by Dr. R. Paterson in the year 1837, "On the Fossil Organic Remains found in the Coal Formation at Wardie, near Newhaven"††. After describing the plants, Dr. Paterson mentions the Entomostraca, which, he says, are to be referred "to the genera *Cypris* and *Daphnoidea*." He adds, on another page, "These microscopic crustaceous remains . . . . . are

* 12mo, 1836, p. 35.

† Trans. R. Soc. Edinb. xxii. p. 401.

‡ Trans. Geol. Soc. Edinb. 1871, ii. pt. 1, p. 82.

§ "On Fossils found in the Rocks underlying the South Side of Edinburgh," Trans. Geol. Soc. Edinb. 1871, ii. pt. 1, p. 138.

‖ Hibbert, *loc. cit.* pp. 179, 180.

¶ Excursions, 1836, p. 35.

** Memoir 32, p. 145.

†† Edinb. New Phil. Journ. 1837, xxiii. pp. 146–155.

to be seen in conjunction with a small shell of the genus *Ostrea*, with Corallines, with plants to be referred to the genus *Fucoides*, as well as with the multitude of terrestrial plants." William Hutton contributed an article, "Note upon the Burdiehouse Limestone," to the joint work by himself and Dr. Lindley *, in which he describes the great abundance of the *Cypris* in that particular bed; he says, "we find, in the utmost profusion, so as even in some parts to make the rock almost oolitic, the shells of *Cypris*, with other minute Entomostraca &c." Only two species of Ostracoda are mentioned by Prof. T. Rupert Jones and Mr. J. W. Kirkby in their paper "On the Entomostraca of the Carboniferous Rocks of Scotland" †, as occurring in the Burdiehouse Limestone, viz. *Beyrichia subarcuata*, Jones, and *Leperditia Okeni*, Münster, although Prof. Jones added to these in 1871, in two papers bearing the titles "On a new Locality for *Leaia*" ‡ and "On some Bivalved Entomostraca from the Coal-measures of S. Wales." *Leaia* was discovered by Mr. C. W. Peach in an ironstone nodule at Wardie, on the Firth of Forth, in the Wardie-shale section of the Cement-stone group. In an Appendix to the second of the foregoing papers a new *Estheria* (*E. Peachii*) was briefly described §. It was discovered by Mr. D. Grieve, F.G.S., at Camston Quarry, Arthur's Seat, in beds referable, according to Prof. Geikie, to the upper portion of the Red Sandstone group. The occurrence of both the *Leaia* and the *Estheria* were brought under the notice of the British Association in 1871, by Mr. C. W. Peach, in a paper "On additions to the List of Fossils and Localities of the Carboniferous Formations in and around Edinburgh" ‖. At the same Meeting an interesting discovery of "Fossiliferous Strata at Lochend" near Edinburgh was announced by Mr. D. Grieve, who found, in an indurated shale, plants and "a crustacean, *Cypris scoto-burdigalensis*, or an allied species" ¶.

Polyzoa.—I am unacquainted with any published notice of the the occurrence of Polyzoa in the Edinburgh Lower Carboniferous rocks.

Brachiopoda.—In Mr. T. Davidson's paper on "Scottish Carboniferous Brachiopoda," the only locality mentioned as yielding brachiopods which can with certainty be referred to a Lower Carboniferous horizon is the before-mentioned locality Wardie, where *Lingula squamiformis* is obtained **. Mr. Salter also quotes it from the same place ††.

Pelecypoda (*Lamellibranchiata*).—Dr. Hibbert discovered a bivalve in shale above the Burdiehouse Limestone, which he figured under the name of *Unio nuciformis* ‡‡; it, with other fossils, was reproduced by Dr. W. Rhind, and ultimately referred to the genus *Anthracosia* by Salter §§. In 1838, Dr. W. Rhind published another

* Fossil Flora of Gt. Brit. 1837, iii. pp. 22–35.
† Trans. Geol. Soc. Glasgow, ii. p. 213.
‡ Geol. Mag. vii. p. 96.
§ *Ibid.* p. 214.
‖ Brit. Assoc. Report, 1871, pt. 2, p. 109.
¶ *Ibid.* p. 98.
** Geologist, iii. p. 264.
†† Memoir 32, p. 146.
‡‡ Hibbert, *loc. cit.* p. 245.
§§ Salter, *loc. cit.* p. 146.

little work, 'The Age of the Earth'*, in which he devoted a portion of plate ii. to the illustration of some Lower-Carboniferous fossils from the Water of Leith. The name *Axinus pentlandicus* was adopted by Dr. Rhind for what I take to be two specifically distinct shells: one of these, fig. *b*, was afterwards described and figured, without reference to Rhind's book, by Captain T. Brown, as *Pachyodon pyramidatus*, in a paper "On some new Species of the genus *Pachyodon*"†; the other, fig. *a*, is probably Brown's *Pachyodon nucleus* of the same paper. Brown's shells were found in "coal shale at Woodhall, on the north side of the Pentland Hills." It is almost unnecessary for me to observe that there is no coal shale at Woodhall. Fig. *g* of Dr. Rhind's plate is that of a *Modiola*, afterwards described by Capt. Brown as *Avicula modioliforme* in his 'Fossil Conchology,' where he also redescribed the two previous shells (*Pachyodon pyramidatus* and *P. nucleus*), but referred them to *Unio* ‡. In the previously quoted paper by the Rev. T. Brown, on the Carboniferous rocks of the Fifeshire coast, Mr. Salter gave a figure of a new species of *Schizodus* found by Mr. Brown to be plentifully distributed throughout the Fifeshire lower series. The late Dr. Fleming obtained the same shell at Colinton, water of Leith, and would have referred it to *Anatina attenuata*, M'Coy; but Mr. Salter, on examining the hinge, pronounced it a *Schizodus* §. I have since described this shell as *S. Salteri* ||, in memory of my late friend; and when so doing I pointed out that it was probably identical with *Pachyodon pyramidatus*, Brown, and *Axinus pentlandicus* (fig. *b*), Rhind; but as both these authors appear to have figured imperfect examples of these shells, the matter must remain in a state of uncertainty, until an appeal can be made to their original specimens. Four species of bivalves are recorded in the Survey Memoir by Mr. Salter—the *Avicula modioliforme*, Brown, a thin-shelled species of *Anthracomya*? from the Wardie Shales, the *Anthracosia*? (*Unio*) *nuciformis* from the Burdiehouse Limestone, and an oval species of *Myalina* from the Clubbidean basement-beds of the Cement-stone group ¶. In a short paper of my own, published in 1875, I described the shell I have here mentioned under the name of *Schizodus Salteri* **. I was supplied by my friend Dr. Traquair with some good interiors; and by means of these, in conjunction with the original specimens kindly lent me by the Rev. Mr. Brown, the hinge-structure of the species was satisfactorily worked out. Dr. Traquair, at the same time, lent me specimens of the *Modiola* figured by Dr. Rhind, from which I was able to show its identity with *Myalina crassa*, Fleming. In a paper I communicated to the 'Annals and Magazine of Natural

* 12mo, 1838.

† Ann. & Mag. Nat. Hist. 1843, xii. p. 390, pl. 16*.

‡ Illustrations of the Foss. Conch. Gt. Brit. 1849, pp. 162, 178, 179, pls. 66* and 73.

§ Trans. R. Soc. Edinb. xxii. p. 392.

|| Ann. & Mag. Nat. Hist. 1875, xv. p. 431.

¶ Memoir 32, p. 146.

** Annals, *loc. cit.*

History' in August last year * a shell was described as *Leptodomus? clavatus*, which is common at four localities—Woodhall, Granton, Drumsheugh, and Craigleith. Some further remarks are made upon this species further on. The base of the Cement-stone group at the Clubbidean Reservoir in the Pentland Hills appears to be well marked by the presence of a limestone in which a bivalve occurs referred by Mr. Salter to the genus *Myalina*. I have never seen good specimens of this form. A thin papyraceous little shell is very characteristic of the Wardie Shales at Slateford, of which numerous specimens are in the Survey Collection. By Mr. Salter it was regarded as an *Anthracomya* †; I have labelled it *Anthracoptera papyracea*, R. Eth. (MS.). In the 'Geological Magazine' for June last (1877) I described another bivalve, equally characteristic of the beds in connexion with the Burdiehouse Limestone, as *Anthracomya scotica* ‡.

Gasteropoda.—No members of this class had been described from our Lower Carboniferous rocks, so far as I am aware, until I noticed the occurrence of a variety of *Bellerophon decussatus*, Flem., at Woodhall, Water of Leith §.

Cephalopoda.—Mr. Salter recorded two species of *Orthoceras* from Livingston, near Mid Calder. I am not aware that any other specimens have been found in that immediate locality.

II. *Descriptions of the Species from the Wardie-Shale section of the Cement-stone group contained in the Cabinets of Mr. John Henderson and Mr. Gall, Edinburgh.*

With the exception of a few of the specimens, the species described in the following pages are in the cabinet of Mr. J. Henderson, who has collected extensively from the Wardie Shales, and has been kind enough to place his collections at my disposal for description. I am also indebted to Mr. Gall, through Mr. Henderson, for the loan of several additional specimens from the same beds. I must not omit to mention that Mr. James Bennie has made an extensive collection, not only from the Wardie-Shale division, but also from the other horizons of the Lower Carboniferous. In working out Mr. Henderson's fossils the examination of the Survey Collection has been of great assistance to me; and could I have combined the description of the latter with the present notes, the number of species from the Lower Carboniferous generally would be greatly increased, and the conclusions arrived at of a more extended and complete character.

I have experienced considerable difficulty in the discrimination of some of the species, not only from the usually bad state of preservation in which the specimens are found, but also from the want of works bearing on similar deposits and their contents elsewhere.

* "Notes on Carboniferous Lamellibranchiata," vol. xviii. 4th series, p. 101.
† Memoir 32, p. 146. ‡ Dec. 2, iv. p. 244, t. 12. fig. 8.
§ Geol. Mag. Dec. 2, iii. p. 244.

This has rendered necessary the establishment of several new species, although I have endeavoured to avoid this as much as possible.

The occurrence of beds of shale, in the Calciferous Sandstone series of this neighbourhood, with fossils of a decidedly marine facies has, I think, been little noticed. That containing the greatest variety of species, the Woodhall Shale, was in all probability known to the earlier geological explorers of Edinburgh; but its very marked marine character was not so definitely ascertained until its exploration was undertaken by Messrs. Henderson and Bennie. Dr. Page read a paper at the British-Association Meeting in 1855 "On the Freshwater Limestone of Dr. Hibbert," in which he insisted that, although the Burdiehouse Limestone in its palæontological features was of undoubted freshwater origin, still in the series there are bands containing marine fossils *—a point which has been fully borne out by later researches. Mr. Henderson has obtained from the Woodhall shale at least 17 well-defined species, and Mr. Bennie about the same number. Of these, 10 are afterwards met with and become characteristic of the true marine Carboniferous Limestone, and 3 or 4 doubtfully so.

Description of the Species.

Class ACTINOZOA.

Order Tabulata.

Genus Chætetes, Fischer.

Chætetes, sp. ind. Pl. II. figs. 33 & 33 *a*.

Sp. char. Corallum forming an irregular, thin, incrusting expansion, composed of very short hexagonal or polygonal tubes; angles of the tubes, or calicles, bearing a small, rounded, and blunt mamelon or "monticule."

Obs. My friend Prof. H. A. Nicholson, who has devoted much time to the elucidation of the species of this genus, agrees with me in regarding this as probably a *Chætetes*, more especially as distinct "monticules" are visible. He thinks it (and I quite agree with him) an open question whether some of the incrusting species referred to this genus are not truly Polyzoa.

Loc. and Horizon. Shale with other marine fossils below the weir of Woodhall Barley-mill, Water of Leith, at Juniper Green, near Edinburgh, incrusting Orthoceratites. In the Wardie-Shale section of the Cement-stone group.

* Brit. Assoc. Report for 1855, pt. 2, p. 91.

Class ANNELIDA.

Order Tubicola.

Genus Spirorbis, Lamarck.

Spirorbis, Lamarck, 1818, Hist. Nat. Anim. sans Vertèbres, v. p. 358.

Spirorbis carbonarius, Murchison. Pl. I. figs. 1 & 2.

Microconchus carbonarius, Murch. Sil. Syst. 1839, p. 84, f. D 1–10.
Spirorbis carbonarius, Murch. Siluria, 1867, 4th ed. p. 302, Foss. 83.

Sp. char. Tube attached by one side, forming a more or less closed helix of from $1\frac{1}{2}$ to 3 turns, not all in the same plane, increasing in size slowly towards the aperture, and dextral; umbilicus deep; aperture oval or circular, sometimes extended into a short free tube. Ornamentation consisting of unequal ridges of growth, with intervening microscopic spiral striæ.

Obs. This is so variable a species that I have been able to distinguish no less than four, or perhaps five, well-marked varieties in a large collection of specimens which has lately passed through my hands, besides Mr. Henderson's specimens. The above description applies only to the latter, and would require to be somewhat extended to include the varieties. Another point to be determined is the relation this species bears to *Spiroglyphus marginatus*, M'Coy, as it frequently forms a distinct groove for itself on the organism to which it is attached.

Loc. and Horizon. In black bituminous shale at Katesmill, above Colinton, Water of Leith, associated with *Anthracomya scotica*, R. Eth., Jun. In entomostracan shale, adhering to indeterminable bivalve shells at Woodhall, Water of Leith. Both horizons in the Wardie-Shale division of the Cement-stone group.

Genus Serpulites, Macleay.

Serpulites, Macleay, 1839, Murchison's Silurian System, p. 700.

Serpulites carbonarius, M'Coy. Pl. I. fig. 3.

Serpulites carbonarius, M'Coy, Synop. Carb. Foss. Ireland, 1844, p. 170, t. 23. f. 32.

Sp. char. Tube small, compressed, shelly, terminating posteriorly in two lengthened cylindrical tubes, the prolongation of the lateral thickened ridges (*M'Coy*).

Obs. The posterior cylindrical tubes are not preserved; but the lateral thickened ridges are quite clear. Prof. M'Coy describes the tube as shelly; but I am satisfied that a certain amount of horny matter also entered into its composition. The longitudinal wrinkles on the surface of the tube are sufficiently fine to pass for striæ.

Loc. and Horizon. In a bed of marine shale, below the ford at the weir of Woodhall Mill, Juniper Green, in the Wardie-Shale section of the Cement-stone group.

Class BRACHIOPODA.

Genus Discina, Lamarck.

Discina nitida, J. Phillips. Pl. I. figs. 4–6.

Orbicula nitida, J. Phill. Geol. Yorkshire, 1836, ii. p. 221, t. 9. f. 10–13.

Discina nitida, Davidson, Mon. Brit. Carb. Brachiopoda, Pal. Soc. p. 179, t. 48. f. 18–25.

Obs. A small depressed variety of this species has been found at two localities by Mr. Henderson. When the specimens are collected, the slightest touch usually destroys the whole of the shelly matter.

Loc. and Horizon. In a hardened shale, associated with Lamellibranchs, quarry on the north side of the Colinton road, under Craiglockhart Hill, near Edinburgh; in shale with other marine fossils at Woodhall, as before.

Genus Lingula, Bruguière.

Lingula squamiformis, J. Phillips. Pl. I. fig. 7 (and fig. 8?).

Lingula squamiformis, J. Phill. Geol. Yorkshire, 1836, ii. p. 221, t. 9. f. 14; Davidson, Mon. Brit. Carb. Brach., Pal. Soc. p. 205, t. 49. f. 1–10.

Obs. This species was first recorded from the Cement-stone group by Mr. T. Davidson *, and afterwards by the late Mr. Salter †. They give Wardie, on the shore of the Firth of Forth, between Leith and Granton, as the locality. In addition to one of the following localities, Mr. James Bennie has obtained *L. squamiformis* at two other localities in the neighbourhood of Mid Calder.

Loc. and Horizon. In hardened shale at quarry under Craiglockhart Hill (?), associated with *Lingula mytiloides*; in black shale in the Water of Leith at Dean Bridge, Edinburgh, Wardie-Shale division of the Cement-stone group.

Lingula mytiloides, J. Sowerby. Pl. I. figs. 9, 10.

Lingula mytiloides, J. Sow. Min. Con. 1813, i. p. 55, t. 19. f. 1, 2; Davidson, Mon. Brit. Carb. Brach. Pal. Soc. p. 207, t. 48. f. 29–36.

Obs. Previous to seeing the specimens in Mr. Henderson's Cabinet, I had examined a few obtained by Mr. Bennie, on behalf of the Geological Survey, at Craigleith Quarry, and had submitted

* Geologist, 1860, iii. p. 264.
† Mem. Geol. Survey Scot. No. 32, 1861, p. 146.

them to Mr. T. Davidson, F.R.S., who was kind enough to favour me with the following reply to my letter:—"As you say, one or two of them look like a small variety of *L. squamiformis*. This last is, however, a much larger shell; and I would almost feel inclined to refer them to *L. mytiloides*." The present individuals so closely resemble those, that, although they are in any thing but a good state of preservation, I do not hesitate to refer them to the same species.

Loc. and Horizon. In hardened shale, quarry under Craiglockhart Hill, as before; in shale with other marine fossils at Woodhall Mill, as before; in shale above the sandstone at Craigleith Quarry, near Edinburgh.

Class PELECYPODA (LAMELLIBRANCHIATA).

Genus Avicula, Klein.

Avicula Hendersoni, sp. nov. Pl. I. fig. 11.

Sp. char. Obliquely transversely elongated, very inequilateral. Anterior end well marked, divided off by the byssal sinus; posterior end produced, obtusely rounded; posterior wing flattened, falciform; hinge-line straight, not so long as the shell; ventral margin subparallel with the hinge-line, indented by the byssal notch, otherwise convex. Posterior slope well marked, obtusely rounded; byssal sinus extending from the beak as a pronounced groove in each valve; widening towards the ventral margin. Umbones anterior, prominent. Surface of both the body of the shell and the posterior wing covered with very regular concentric imbricating striæ.

Obs. Avicula Hendersoni is closely allied to several Irish species figured by Prof. M'Coy *, and seems to be nearest to his *A. angusta*, but with the dorsal and ventral margins much more nearly parallel than in the latter, in this respect corresponding more closely with *A. recta*, M'Coy, and *A. gibbosa*, M'Coy, from which, however, it otherwise differs considerably. I name the species after Mr. Henderson, to whom I am indebted for the loan of the majority of the specimens described in this communication.

Loc. and Horizon. In a hard Cyprid shale, quarry on the north side of the Colinton road, under Craiglockhart Hill, near Edinburgh, near the base of the Cement-stone group; in shale with marine fossils at Woodhall, as before.

Genus Aviculopecten, M'Coy.

Aviculopecten, M'Coy, 1851, Ann. & Mag. Nat. Hist. vii. p. 171.

Aviculopecten, sp.

Obs. A portion of one valve has been obtained from the Woodhall Shale. It is a radiately striated species, with the ribs crossed by

* Synop. Carb. Foss. Ireland, t. xiii. f. 20.

fine close concentric striæ, or else toothed, especially on the only remaining ear.

Loc. and Horizon. In shale, with other marine fossils, at Woodhall Mill, as before.

Genus ANTHRACOPTERA, Salter.

Anthracoptera, Salter, 1862, Mem. Geol. Survey, Country around Wigan, p. 37.

Gen. char. Shell aviculiform, very slightly inequivalve, with a slight byssal notch in both valves; left valve the most convex. Hinge-line with a thickened margin, but no hinge-plate of any kind; there is an obscure tooth in the anterior part of the hinge, but no lateral teeth. Posterior adductor scar large and subcentral; anterior scar small, umbonal, with at least two supplementary scars; shell thin, with a puckered or plaited epidermis. (*Salter.*)

Obs. The genus *Anthracoptera* was proposed by the late Mr. Salter to include numerous Coal-measure shells "hitherto called *Myalina* or *Avicula* with doubt, but evidently distinct from one and the other of these genera. They have not the unequal valves of *Avicula* nor the striated hinge-plate of *Myalina*, nor indeed any hinge-plate at all." I now propose to place in this genus, in addition to the Coal-measure fossils for which it was established, some bivalves from the Lower Carboniferous rocks of this neighbourhood, of which the internal characters of the shell, so far as I have been able to make them out, appear to have more in common with this genus than with *Myalina*. About two or three years before Mr. Salter proposed his name, Dr. Dawson established his genus *Naiadites* for similar shells, characteristic of the South-Joggins Coal-measures, Nova Scotia. In a paper on "Fossil Shells from the Coal-measures of Nova Scotia"*, Mr. Salter pointed out the synonymy of the two names, and claimed for his own precedence over that of Dr. Dawson on the ground of more complete description. *Anthracoptera* appears to have been regarded by Salter as one of either the Aviculidæ or Mytilidæ, whilst by Dr. Geinitz the typical American species, *A.* (*Naiadites*) *carbonaria*, Dawson, is looked upon as a *Dreissena* †. The affinity of these shells has been discussed by Dr. Dawson at some length; he considers them to be brackish-water shells allied to the Mytilidæ, or embryonic forms of Unionidæ ‡, and states that the structure of the shell is similar to that of the latter family.

ANTHRACOPTERA ? OBESA, sp. nov. Pl. I. figs. 12, 13 (& 14 ?).

Sp. char. Trigonal, very gibbous, inequality of the valves distinctly marked; anterior side pointed, well marked, and defined by the byssal furrow in each valve; posterior side but little flattened, its

* Quart. Journ. Geol. Soc. xix. p. 80.
† N. Jahrbuch, 1864, p. 654; Geol. Mag. 1865, ii. p. 205.
‡ Acadian Geology, 1867, p. 203.

margin slightly sigmoidal. Hinge-line straight, as long as the shell, its margin thickened on each valve, leaving in casts two long grooves. Umbones well developed, contiguous, but not touching, anterior, but not quite terminal, with a broad, very obtusely rounded diagonal ridge proceeding from each, to which the shell owes much of its exceedingly convex form. Byssal furrows shallow, most pronounced in the left valve; marginal notch not deeply excavated. Anterior muscular impressions quite anterior, infra-umbonal. Surface of the shell covered with concentric subimbricating lamellæ, crowded and striiform on the anterior end, but opening out and becoming lamellar on the diagonal ridge and posterior wing.

Obs. The shells comprised in this species very much resemble some *Myalinæ*; but I believe I am more justified in referring them to the present genus than to *Myalina*, of the striated hinge-plate of which I can find no trace; neither has any definite evidence presented itself which would warrant me in placing them in either *Avicula or Pterinea.* The much more central position of the diagonal ridge, greater convexity of the shell, and the sigmoidal margin of the posterior end at once distinguish *A. obesa* from either *Anthracoptera*? or *Myalina* (*Avicula*) *quadrata*, Sow., *A.*? or *M.* (*Avicula*) *modiolaris*, Sow., *A.*? or *M.* (*Modiola*) *carinata*, Sow. *, or *Anthracoptera*? *Browniana*, Salter (=*Avicula tenua*, Brown). I am not acquainted, and so cannot institute a comparison, with any of those Coal-measure fossils figured by Captain T. Brown in his 'Fossil Conchology' †, many of which will doubtless fall into the genus *Anthracoptera*; but *A. obesa* appears to be quite distinct.

Loc. and Horizon. In a bed of hard micaceous sandstone, Drumsheugh, Water of Leith, at Dean Bridge, Edinburgh, Wardie-Shale division of the Cement-stone group; in altered shale underlying trap, Corstorphine Hill, near Edinburgh; in a band of limestone above the sandstone at Craigleith Quarry, near Edinburgh?

Genus Myalina, De Koninck.

Myalina, De Koninck, Anim. Foss. Terr. Carb. Belgique, p. 125.

Myalina crassa, Fleming (non G. & F. Sandberger).

Var. *modioliformis*, Brown.

Obs. In the 'Annals and Magazine of Natural History' for June 1875 I described a series of specimens of *M. crassa*, Flem., from the Fife Carboniferous-Limestone series and the Lower Carboniferous of this neighbourhood, and gave the synonymy of the species as then known to me. I remarked on the slighter make of the latter as compared with the Fife examples. I find that the Water-of-Leith shells from the Lower Carboniferous rocks were described

* In one place Mr. Salter referred these species to *Myalina* (Iron Ores Gt. Britain, 1861, pt. 3, p. 228), in another with doubt to *Anthracomya* (*ibid.* p. 230), and again in a third to *Anthracoptera* (Oldham Memoir, 1864, p. 64). He appears to have been in great doubt as to their true generic affinity.

† Plate 62.

many years ago by Captain Thomas Brown as *Avicula modioliforme*; but as I cannot distinguish any characters, either external or internal, by which to specifically distinguish Captain Brown's shell from Dr. Fleming's, I propose to adopt the name given by the former as a varietal designation for the thinner and lighter form of *M. crassa*. To the synonymy already given must therefore be added:—

Avicula modioliforme, Brown, Foss. Conchology, 1849, p. 162, pl. 66. fig. 19.
" " Morris, Cat. Brit. Foss. 1854, 2nd ed., p. 162.
" " Salter, Mem. Geol. Survey Scotl. No. 32, 1861, p. 146.

A specimen from Fifeshire obtained since my paper was written exhibits another character not hitherto figured, a series of minute pits (? muscular-fibre-pits) running from above the double umbonal anterior muscular scars along the edge of the thickened hinge-area backwards. This is also visible in a specimen from the Water of Leith which has lately come under my notice; but here the pits are shallower, wider, and further removed from the edge of the hinge-area.

Loc. and Horizon. Forming a bed of shale with *Schizodus Salteri*, above and below the shale with marine fossils, at Woodhall, as before.

MYALINA SUBLAMELLOSA, sp. nov. Pl. I. fig. 15, and Pl. II. figs. 16, 17.

Sp. char. Trigonal; anterior side small, truncated, with a slightly sigmoidal margin, descending from the beak at rather less than a right angle; posterior end expanded, flattened, with its margin slightly convex or subtruncate. Hinge-line somewhat depressed, a little less than the width of the shell, the angle formed by the union of the hinge-line and posterior margin an obtuse one. Beaks sharp, terminal, curved anteriorly, with a slightly prominent sigmoidal ridge extending from each down the anterior side and close to its margin; ventral margin convex. Shell ornamented with concentric lines of growth.

Obs. This species may be compared with *Mytilus Flemingii*, M'Coy *, *Myalina lamellosa*, De Kon. †, *Myalina perattenuata*, Meek and Hayden ‡, and *M. meliniformis*, Meek and Worthen §; but its greatest affinity is with the first two of these. From *Mytilus Flemingii* it may be distinguished by possessing a smaller and more truncated anterior end, the bounding ridge from the beaks being less posterior in position, a less-depressed and shorter hinge-line, and a more broadly rounded ventral margin. From *Myalina lamellosa*,

* Synop. Carb. Foss. Ireland, p. 76, pl. xi. fig. 29.
† Anim. Foss. Terr. Carb. Belgique, p. 126, t. 3. fig. 6.
‡ Geol. Rep. Illinois, v. p. 582, t. xxvi. fig. 11.
§ *Ibid.* ii. p. 343, t. xxvii. fig. 3.

the shell under consideration may be known by the slightly sigmoidal outline of its anterior end, and its less-depressed hinge-line—characters which, when taken together, give a different appearance to *M. sublamellosa* from that possessed by *M. lamellosa*. It also bears a general resemblance to the *Myalinæ* figured by Prof. W. King from the Permian rocks of England.

Loc. and Horizon. In hardened Cyprid shale, quarry under Craiglockhart Hill, on north side of the Colinton Road near Edinburgh; Cement-stone group.

Genus Nuculana, Link, = Leda, Schumacher.

Nuculana Sharmani, sp. nov. Pl. II. fig. 18.

Sp. char. Transversely elongated, slightly clavate, moderately convex. Anterior end rounded; posterior end produced, gradually compressed laterally to the bluntly rounded point. Ventral margin convex, sloping upwards posteriorly. Umbones nearly but not quite central, a little anterior; lunule probably small and ill-defined; escutcheon or posterior lunette narrow, and not deeply marked, or bounded by ridges from the beak. Surface of the valves ornamented with imbricating striæ; on the posterior end these striæ widen out, become coarser and broader, and assume the aspect of small waves or fluctuations.

Obs. From *Leda attenuata*, Fleming, the present species is distinguished by the more central position of the beaks, and much more equal-sided appearance of the shell, blunter termination of the posterior end, and smaller and narrower escutcheon. From *Nucula* (or *Leda*?) *birostrata*, M'Coy *, it is distinguished by its straighter posterior end and larger antero-ventral development; from *Nucula* (or *Leda*?) *clavata*, M'Coy †, by the more central position of the beaks, and longer anterior end. From *Nucula* (or *Leda*?) *leiorhynchus*, M'Coy ‡, the ornamentation of the posterior end will at once distinguish it. *Leda intermedia*, mihi, is a far more laterally compressed shell; and the posterior end is less attenuated than in *N. Sharmani*. The arched and very clavate form of *L. Traquairii*, mihi, may be taken as a distinctive character between it and the present species. I name the species with much pleasure after my friend Mr. G. Sharman, Assistant Palæontologist to the Geological Survey.

Loc. and Horizon. In shale with marine fossils, at Woodhall, as before.

Genus Schizodus, King.

Schizodus, King, 1844, Ann. & Mag. Nat. Hist. xiv. p. 313; Permian Foss. England, 1850, p. 185.

* Synopsis Carb. Foss. Ireland, 1844, p. 68, pl. xi. fig. 23.
† *Ibid.* p. 69, pl. xi. fig. 25.
‡ *Ibid.* p. 69, pl. xi. fig. 27.

SCHIZODUS SALTERI, R. Etheridge, Jun. Pl. II. fig. 19.

Schizodus Salteri, R. Eth., Jun., Ann. & Mag. Nat. Hist. 1875, xv. p. 431, pl. 20. figs. 6–9.

The examples from the Lower Carboniferous of this neighbourhood do not essentially differ from Fifeshire specimens, except perhaps that the concentric striæ are a little less marked.

Loc. and Horizon. In shale with marine fossils at Woodhall, as before. In a shelly ironstone at Drumsheugh, Water of Leith, at Dean Bridge, near Edinburgh; in shale, with other marine fossils, behind West Breakwater, Granton; in ditto at Craigleith Quarry, above the sandstone.

Genus ANTHRACOSIA, King.

Anthracosia, King, 1844, Ann. & Mag. Nat. Hist. xiv. p. 313.

ANTHRACOSIA? (UNIO) NUCLEUS, Brown? Pl. II. fig. 20.

Axinus pentlandicus (pars), Rhind, Age of the Earth, 1836, pl. 2. fig. *a*.

Pachyodon nucleus, Brown, Ann. & Mag. Nat. Hist. 1843, xii. p. 394, pl. 16*. fig. 1.

Unio nucleus, Brown, Fossil Conchology, 1849, p. 178, t. 73. fig. 8.

Obs. I have already pointed out* that I believe Dr. Rhind figured two separate species under the name of *Axinus pentlandicus*. One of these figures (fig. *b*) is, I think, the shell now known as *Schizodus Salteri*, mihi. The other (fig. *a*) was that to which Captain T. Brown gave the name of *Pachyodon* (or *Unio*) *nucleus*. The original locality was Woodhall, Water of Leith. A very ill-preserved shell in Mr. Henderson's collection has, so far as can be ascertained, the general outline of *Unio nucleus*; but it is impossible, on the characters afforded by it, to give a description of the species.

Loc. and Horizon. In hardened shale, lowest part of the Cementstone group, quarry on the north side of the Colinton Road, under Craiglockhart Hill, near Edinburgh.

Genus ANTHRACOMYA, Salter.

Anthracomya, Salter, 1861, Iron Ores Gt. Britain, pt. iii. p. 229.

ANTHRACOMYA SCOTICA, R. Eth., Jun.

Anthracomya scotica, R. Eth., Jun., Geol. Mag. 1877, dec. 2. iv. p. 244, t. 12. fig. 8.

Obs. A few fragments which appear referable to this characteristic fossil are in Mr. Henderson's collection. They are much too fragmentary for description or figuring.

Loc. and Horizon. In black shale of the Wardie series, Water of Leith, at Katesmill, near Slateford, Edinburgh.

* Ann. & Mag. Nat. Hist. 1875, xv. p. 432.

Genus Pandora, Bruguière.

Pandora? typica, R. Eth., Jun. Pl. II. figs. 22, 23 (and 21?).

Leptodomus? clavatus, R. Eth., Jun., Ann. & Mag. Nat. Hist. 1876, xviii. p. 102, pl. 4. figs. 9, 10.

Sp. char. Somewhat clavate, a little arcuated, very inequilateral, gibbous in the umbonal region; length much exceeding the height. Anterior side short, convex, its margin rounded; posterior side much more compressed, transversely elongated, its margin sharply truncated; umbones prominent, quite anterior, but the beaks not terminal. A blunt diagonal ridge traverses each valve from the umbo to the posterior ventral angle; posterior slope a little concave. Dorsal margin long, slightly arcuated; dorsal and ventral posterior angles sharp and well defined. Ornamentation consisting of concentric striæ, which are suddenly deflected on reaching the diagonal ridge, and traverse the posterior slope parallel to the posterior margin in a very regular manner.

Obs. My former description of this species was drawn up from crushed specimens; but the acquisition of nearly perfect examples enables me to give a more definite diagnosis. For individuals in the crushed state the characters given in the 'Annals' are quite appropriate; for it is a fact worthy of note that, when crushed, all specimens of this species which have come under my notice appear to be compressed into a similar form and to a like degree the outline becomes more clavate and arcuated, the posterior end recurved and truncated obliquely, the posterior slope still more concave, and divided down its centre by a groove from the beak backwards, and the surface a good deal wrinkled.

The reference to *Pandora* is made exclusively on the close external resemblance this species bears to that genus. I have not seen any of the internal characters; neither can I say whether the shell was inequivalve or not, as it should be if a true *Pandora*. *P.*? *typica* resembles in many respects *Lutraria elongata*, M'Coy *, and to some extent *Pandora clavata*, M'Coy †, and will, perhaps, occupy an intermediate position between the two. I have assigned to the species the name *typica*, from its great prevalency in certain beds of shale in the Cement-stone group around Edinburgh. Mr. Henderson notices its occurrence, under the name of *Pandora* sp., in his paper on the Wardie Shales, previously referred to.

Loc. and Horizon. In the bed of shale at Woodhall, as before; Drumsheugh, near Dean Bridge, in a similar bed; in ditto behind the western breakwater at Granton Harbour; in ditto above the sandstone at Craigleith Quarry. Cabinets of Messrs. Henderson and Gall; and collection Geol. Survey Scotland, collected by Mr. James Bennie.

I also give figures of two undetermined bivalves (figs. 24 & 25) in the collection of Mr. Gall and Mr. Henderson, from Drumsheugh and Water of Leith respectively.

* Synopsis Carb. Foss. Ireland, 1844, p. 52, t. viii. fig. 3.
† *Ibid.* p. 51, t. xi. fig. 1.

Class GASTEROPODA.

Genus Littorina, Férussac.

Littorina scoto-burdigalensis, sp. nov. Pl. II. figs. 26, 27.

Sp. char. Shell conic-oval, imperforate; spire obtusely pointed; whorls four, flattened or shoulder-like immediately below the suture in each whorl, especially the last one; suture distinctly marked, the last whorl twice as large as the other three. Peristome entire; aperture oval, rounded below. Outer lip . . . . ?; inner lip reflected over the spire. Surface of the shell without ornamentation.

Obs. The above description is drawn up from specimens kindly lent by Mr. Gall, through Mr. Henderson. After much consideration, both on my own part and that of my friend Dr. J. C. Purvis, I have provisionally placed this troublesome little shell in the genus *Littorina*. All the specimens I have seen separated from the matrix are, at the best, but imperfectly preserved; but, so far as can be made out, it appears to be a member of the Littorinidæ, and has also perhaps some characters in common with the Paludinidæ. Previous to seeing Mr. Gall's specimens, I had named those in the Survey Collection, in MS., as above, from the fact that the species is the chief component of a thin shelly band at the base of the Burdiehouse Limestone at the Raw Camps Quarries, near Mid Calder. The band in question is locally called "Buckie-fake," and appears to contain little else than this small Gasteropod. The Burdiehouse Limestone is usually considered to be of freshwater, or at the least estuarine origin. Should this species be proved to have more affinity with *Paludina* than with *Littorina*, it will tend to support this hypothesis; still, even if referred to *Littorina*, it will not detract much from the fresh- or brackish-water origin of the Burdiehouse Limestone.

Loc. and Horizon. Drumsheugh, near Dean Bridge, Edinburgh.

Genus Pleurotomaria, Defrance, 1824.

Pleurotomaria monilifera, Phillips?. Pl. II. fig. 28.

Pleurotomaria monilifera, Phill. (1836), Geol. Yorksh. ii. p. 227, t. 15. fig. 10 *a*; De Koninck (1842–45), Anim. Foss. Terr. Carb. Belg. p. 387, t. 34. fig. 2; Brown (1849), Foss. Conch. p. 87, t. 40. figs. 30, 34.

Obs. All the specimens are crushed; but there appear to be traces of the shallow groove of the body-whorl, with its tuberculated bordering keels, characteristic of the species, as described by Prof. De Koninck. There are also indications of spiral and transverse ridges.

Loc. and Horizon. Water of Leith, at Woodhall, in the bed of shale with marine fossils.

Genus MURCHISONIA, D'Archiac & De Verneuil.

Murchisonia, D'Archiac & De Verneuil, 1841, Bull. Soc. Géol. de France, xii. p. 159.

MURCHISONIA STRIATULA, De Koninck ?. Pl. II. fig. 29.

Murchisonia striatula, De Kon. Descr. Anim. Foss. Terr. Carb. Belgique, 1844, p. 415, t. 40. fig. 7.

Obs. Our little shell approaches nearer to Prof. De Koninck's description than to any other I can find. Unless the Woodhall shells are young examples of *M. striatula*, the difference in size is very marked; and, further, the ornamentation does not quite coincide with that of Prof. De Koninck's species. So far as I have been able to discriminate them, the ridges and grooves are less than twelve in number; and the former are separated by more equal spaces than the grooves of *M. striatula* appear to be. The whorls vary in number; Mr. Henderson's specimens possess eight, whilst in the Survey Collection there is one from the same locality, collected by Mr. Bennie, with eleven whorls. *Loxonema polygyra*, M'Coy*, is nearer to the present shells in point of size, but is marked with much too few concentric ridges.

Loc. and Horizon. In the shale with marine fossils at Woodhall, as before.

Genus BELLEROPHON, De Montfort.

BELLEROPHON DECUSSATUS, Fleming, var. *undatus*, R. Eth., Jun. Pl. II. fig. 30.

I described this variety in the 'Geological Magazine' for April (1876)†. It differs from the typical form in having a series of broad obtuse fluctuations or waves in the direction of the transverse striæ. The latter are clearly visible in young specimens; but in older and larger individuals they become obscured or obsolete, or nearly so.

Loc. and Horizon. Woodhall, as before.

Class PTEROPODA.

Genus CONULARIA, Miller.

Conularia (Miller), Sowerby, Mineral Conchology, iii. p. 107.

CONULARIA sp. ind.

Obs. One fragment only has come under my observation in Mr. Henderson's collection; but in the Geological Survey Cabinet there are two others which, although only portions also, afford more information than the other. The specimens represent a part of one of the faces of the pyramid with its median ridge. The transverse

* Synop. Carb. Foss. Ireland, 1844, p. 30, t. iii. fig. 1.
† Decade 2, vol. iii. p. 155, t. vi. figs. 9, 10.

ridges are plain and unornamented, and not in any way denticulated or notched. They unite subalternately with the median ridge, the point of junction being marked by a slight enlargement or button. The flattened interspaces between the transverse ridges are minutely wrinkled vertically. The explanation of this is probably that given by Mr. J. de C. Sowerby, who, in describing *C. quadrisulcata* says: —"Many of the specimens in ironstone have smooth furrows between the crenated ridges; in others the furrows are crossed by striæ; and both these forms may sometimes be found in one specimen, and arise from the presence or absence of a thin dark brown skin or covering, the interior of which is smooth and the exterior wrinkled"*.

Loc. and Horizon. Woodhall, as before.

Class CEPHALOPODA.

Genus Nautilus, Breynius.

Nautilus cariniferus, J. de C. Sowerby?. Pl. II. figs. 31, 32.

Nautilus cariniferus, J. de C. Sow. (1824), Min. Con. v. p. 130, t. 482. figs. 3, 4; Phillips (1836), Geol. Yorksh. ii. p. 232, t. 17. fig. 19; De Koninck, Anim. Foss. Terr. Carb. Belg. p. 549, t. 48. figs. 11, 12; Brown (1849), Foss. Conch. p. 32, t. 22.

Obs. In the impression of the specimen represented by fig. 31, there are distinct traces of the denticulated keels of the above species, still more distinctly seen in the fragment, fig. 32. Were it not for the crenulated ridges or keels, marking a distinctive character, these fragments would scarcely be worth notice; but the paucity of marine life, speaking generally, in the Lower Carboniferous rocks around Edinburgh, renders it necessary to catalogue every fragment exhibiting the slightest trace of definite characters. If the reference to *N. cariniferus* is correct, then Prof. De Koninck's suggestion that the shell was covered with fine transverse striæ is confirmed. These may be seen on a part of the flattened impression, as well as similar longitudinal lines.

Loc. and Horizon. Woodhall, in the shale with other marine fossils, as before.

Nautilus, sp. ind.

Obs. A crushed and compressed example obtained by Mr. Gall at Craigleith, somewhat resembling in general appearance *N. cyclostomus*, Phill.; but, except for the fact that it proves the presence of a *Nautilus* in the band of shale at Craigleith, the specimen is quite useless for specific identification.

Loc. and Horizon. Craigleith Quarry, in shale above the sandstone, Cement-stone group. Cabinet of Mr. Gall.

* Trans. Geol. Soc. 2nd ser. v. (expl. of pl. xl.).

Genus Orthoceras, Breynius.

Orthoceras, sp. ind. Pl. II. figs. 33, 34.

Obs. Mr. Henderson possesses several fragments of this genus, from the Woodhall and Granton shale, which I think may all be referred to one species. The shell tapers gradually, the section is circular, and the siphon small and central. There is a very finely striated epidermal covering, the striæ being very fine, close, and slightly waved; but they must not be confounded with the sharp annular striæ of *O. cinctum*, Sow. These characters correspond tolerably well with the description of *Orthocera cylindracea*, Flem.*; but really so little has been done towards the determination of this and other equally ill-defined Carboniferous Orthoceratites that the reference of mere fragments to any of them is, to say the least of it, unsatisfactory. A revision of the Carboniferous Orthoceratites will, whilst bringing to light some undoubtedly new forms, no doubt tend to abolish quite half the so-called species which have been made, in favour of a few and broad but thoroughly recognizable types.

Loc. and Horizon. Woodhall, as before; Granton, in bed of shale behind western breakwater.

A description of the Invertebrates of the Cement-stone group generally, as developed in the Edinburgh district, and contained in the Collection of the Geological Survey of Scotland, would considerably add to the number of the species described in the foregoing sketch. Unfortunately circumstances over which I have no control prevent me from offering a description of these; and in this instance it is owing to the kindness of Messrs. Henderson and Gall that I am able to so far advance the subject.

The following Table (p.22) has been constructed to show the relative occurrence of the species at the localities cited. It will be observed that no less than 18 species occur in the Woodhall shale, whilst at the Craiglockhart Quarry there are six, two of which have not been observed at Woodhall. At Drumsheugh two of the most characteristic shells of the Woodhall shale occur, viz. *Schizodus Salteri*, mihi, and *Pandora typica*, mihi, accompanied by *Anthracoptera? obesa*, mihi. The latter is very characteristic of certain beds at Craigleith Quarry and Corstorphine Hill, and at the former locality is associated with *P. typica*, in a similar way as at Drumsheugh.

III. *Remarks on the First Appearance of certain Species in the Calciferous Sandstone Series of the Edinburgh district.*

We are in possession of little or no published information concerning the Invertebrate life of the lower division of the Calciferous Sandstone Series, the Red Sandstone group. Entomostraca are found at one or two localities (such as *Estheria Peachii*, Jones, in

* Thomson's Annals of Philosophy, 1875, v. p. 202.

Table showing the Occurrence of the Species hitherto noticed or described from the Lower Carboniferous or Calciferous Sandstone series of the Edinburgh district.

Genus and Species.	Synonyms.	Camston Quarry, Arthur's Seat.	Clubbidean Reservoir.	Craiglockhart-Hill Quarry.	Woodhall, Water of Leith.	Corstorphine Hill.	Kate's Mill, Water of Leith.	Drumsheugh, Water of Leith.	Dean Bridge, Water of Leith.	Craigleith Quarry.	Granton, Firth of Forth.	Wardie, Firth of Forth.	Burdiehouse.	Oakbank Oil Works, Mid Calder.	Livingston.	Pass up to higher Carb. beds.
Spirorbis carbonarius, *Murchison*	Microconchus (*Murch.*)	...	?	...	*	...	*	...	...	...	...	...	*	...	...	*
—— ——, var. *a*, Hibberti, *R. Eth.*	Nautilus (*Hibbert*)	...	...	...	...	...	...	...	...	...	...	...	*			
—— ——, var. *b* (*R. Eth.*).		...	...	...	...	...	...	...	...	...	...	...	...	*	...	?
—— helicteres, *Salter*		...	*	...	...	...	...	...	...	...	...	...	...	...	...	*
Serpulites carbonarius, *M'Coy*		...	...	...	*	...	...	...	...	...	...	...	...	...	...	*
Chætetes, sp. ind. (*R. Eth.*)		...	...	...	*	...	...	...	...	...	...	...	...	...	...	?
Beyrichia subarcuata, *Jones*		...	...	...	...	...	...	...	...	...	...	...	*			
Daphnoidea Hibberti, *Jones*		...	...	...	...	...	...	...	...	...	...	...	*			
Estheria Peachii, *Jones*		*														
Leperditia Okeni, *Münster*, var. scoto-burdigalensis, *Hibbert.*	Cypris (*Hibbert*)	...	*	...	...	...	...	...	...	...	...	...	*	...	...	*

Leaia, sp.												*				*
Discina nitida, *J. Phillips*				*	*											*
Lingula mytiloides, *Sowerby*				*	*					*						*
—— squamiformis, *J. Phillips*				*								*				*
Anthracomya scotica, *R. Eth.*							*						*			?
—— (thin-shelled sp.), *Salter*			*													
Anthracoptera ? obesa, *R. Eth.*						*		*		*				?		
Anthracosia ? nuciformis, *Hibbert* †	Unio (*Hibbert*)												*			
—— ? nucleus, *Brown*	Axinus Pentlandicus, fig. *a* (*Rhind*); Pachyodon (Unio)			*	*											
Avicula Hendersoni, *R. Eth.*				*	*											
Aviculopecten (sp. ind.)					*											*
Myalina crassa, *Fleming*	Avicula modioliforme, *Brown*				*											*
—— sublamellosa, *R. Eth.*				*												?
—— (oval sp), *Salter*			*													
Nuculana Sharmani, *R. Eth.*					*											
Pandora ? typica, *R. Eth.*	Leptodomus ? clavatus, *R. Eth.*				*			*		*	*					?
Schizodus Salteri, *R. Eth.*	? Axinus Pentlandicus, fig. *b* (*Rhind*); ? Pachyodon (Unio) pyramidatus, *Brown*				*			*		*	*					?
Bellerophon decussatus, *Flem.* var. undatus, *R. Eth.*					*											*
Littorina ? scoto-burdigalensis, *R. Eth.*							*	*								
Murchisonia striatula, *De Koninck* ?					*											*
Pleurotomaria monilifera, *J. Phillips* ?					*											*
Conularia, sp. ind.					*											?
Nautilus cariniferus, *J. Sowerby* ?					*											*
——, sp. ind.										*						?
Orthoceras attenuatum, *Fleming*															*	*
—— cylindraceum, *Fleming*															*	*
——, sp. ind. (probably ditto)					*					*	*					

† Perhaps identical with *A. scotica*, R. Eth.

the Arthur's-Seat beds); but at present these appear to be all we know of. Proceeding upwards, however, we meet with some debatable beds of sandstone and shale resting on the felstones of Warklaw Hill along the north flank of the Pentland Hills *, which Prof. Geikie informs me he is inclined to place at the base of the Cement-stone group. These beds, where cut by the Clubbidean Burn, contain *Sphenopteris affinis*, L. & H., *Leperditia scoto-burdigalensis*, Hibbert, and a crushed bivalve which Mr. Salter considered an oval species of *Myalina* †. In the south bank of the Clubbidean Reservoir a limestone of the same set of beds is seen to be almost entirely made up of *Spirorbis helicteres*, Salter, with *Sp. carbonarius,* Murchison. This appears to be the first appearance of which we have any record of Pelecypoda and Annelida in the Lower Carboniferous of this district, and was regarded by Mr. Salter as indicative of marine conditions ‡. In some shales overlying the Greenstone of Craiglockhart Hill, seen in an old quarry on the north side of the Colinton road, near Edinburgh, a more copious fauna has been found by Mr. Henderson. We there meet with *Discina nitida,* Phill., *Lingula squamiformis*, Phill.?, *L. mytiloides,* Sow., *Avicula Hendersoni*, mihi, *Myalina sublamellosa,* mihi, and *Anthracosia* ? *nucleus*, Brown.

On passing to the strata more properly known as the Wardie Shales, we meet with a still further increase in the life of the Lower Carboniferous. The Annelida are augmented by the appearance of *Serpulites carbonarius*, M'Coy, at Woodhall. The Actinozoa also first put in an appearance in this horizon ; for we find many of the Orthoceratites occurring in the Woodhall shale covered with a parasitic *Chætetes.* Brachiopoda had previously been recorded from the Wardie Shales, as before stated, by Mr. Davidson and Mr. Salter, in the form of *Lingula squamiformis* at Wardie. A well-marked example of this species has been obtained by Mr. Henderson in the Water of Leith at the Dean Bridge, Edinburgh; whilst *Lingula mytiloides* has passed from the Craiglockhart Shale to the Woodhall horizon, accompanied by *Avicula Hendersoni.* The occurrence at Juniper Green of the frequently-mentioned bed of shale below the ford at Woodhall Mill brings us, perhaps, to one of the most important points in connexion with the Carboniferous geology of the south-east of Scotland; for we here meet with the first appearance of several species of marine shells which pass upwards from these beds and ultimately become some of the most characteristic fossils of the Carboniferous Limestone. The species contained in this bed which have previously made their appearance are *Spirorbis carbonarius*, *Discina nitida*, *Lingula mytiloides*, and *Avicula Hendersoni.* Those which first make their appearance here are *Chætetes*, sp. ind., *Serpulites carbonarius*, *Aviculopecten*, sp. ind., *Myalina crassa*, Flem., var., *Schizodus Salteri*, *Pandora typica*, *Pleurotomaria monilifera* ?, *Murchisonia striatula* ?, *Bellerophon decussatus*, Flem., var., *Conularia*, sp. ind., *Nautilus cariniferus*?, and *Orthoceras*. One species, *Nuculana Sharmani*, is peculiar to this bed.

* Memoir 32, p. 18. † *Ibid.* ‡ *Ibid.* p. 144.

At Drumsheugh, Dean Bridge, certain beds of sandstone and shale have been investigated by Mr. Henderson and Mr. Gall; and the fossil contents go far, I think, to prove Mr. Henderson's view of the identity of this bed with the Woodhall Shale, as amongst them are two of the most characteristic shells of the latter bed, *Schizodus Salteri* and *Pandora ? typica*. Another species accompanying them, but not found at Woodhall, is *Anthracoptera ? obesa*, mihi, which also occurs at Craigleith Quarry, and has been obtained by Mr. Henderson, and also by Mr. Bennie, in an altered shale underlying trap at the north end of Corstorphine Hill, near Edinburgh. A shell which afterwards becomes exceedingly characteristic of the Burdiehouse beds makes its first appearance in black shale in the Water of Leith at Kate's Mill near Slateford. I have elsewhere described this species as *Anthracomya scotica*, and shown that it may be identical with *Unio nuciformis*, Hibbert; but as I cannot trace the type of the latter, it is a question which will, I am afraid, remain unsettled. Mr. Henderson has only obtained fragments from Kate's Mill; but even these are infested with the little *Spirorbis carbonarius*, as are nearly all the individuals from the horizon of the Burdiehouse Limestone. The most interesting point in connexion with the Entomostraca of the Wardie Shales is the first appearance of the Coal-measure genus *Leaia*, for the discovery of which we are indebted to Mr. C. W. Peach, in an ironstone nodule at Wardie. Little has been written on the Invertebrates of the Burdiehouse Limestone and associated beds. They appear to be chiefly remarkable for the abundance of *Spirorbis carbonarius* and its varieties, the *Anthracomya* previously indicated, and the great quantity of Ostracoda forming what is usually termed "Cyprid Shale." The more important forms are *Leperditia scoto-burdigalensis*, Hibbert, *L. Okeni*, Münster, and *Daphnoidea* (or *Cypridina*) *Hibberti*, Jones. It is hardly necessary to point out, as the previous Table sufficiently indicates it, the close correspondence which exists between the organic remains from the bands of marine shale found at Woodhall, Drumsheugh, Craigleith, Craiglockhart, and Granton.

Conclusion.

In the foregoing pages I have endeavoured to give, first, an outline of our knowledge of the Invertebrate fauna of the Calciferous Sandstone Series up to the present time; secondly, I have given descriptions and figures of numerous species from Mr. Henderson's collection, thereby increasing the fauna largely; thirdly, I have appended some remarks on the first appearance of many of these fossils, and indicated the occurrence of, at least, three or four marine beds in the Calciferous Sandstone Series, in addition to that mentioned by Mr. Salter at Clubbidean. They are:—Craiglockhart Quarry with *Discina nitida*, *Lingula squamiformis* ?, *L. mytiloides*, &c.; Woodhall, Water of Leith, with a copious fauna (see Table); and (if not identical with the latter) Drumsheugh; whilst the fourth may perhaps be indicated by the occurrence of *Lingula squamiformis* at Dean Bridge, Water of Leith.

In relation to the first appearance of species, I have shown the occurrence, low down in the Calciferous Sandstone Series, of fossils which afterwards attain their greatest development in, and become characteristic of, the Carboniferous Limestone Series.

EXPLANATION OF PLATES I. & II.

Fig. 1. *Spirorbis carbonarius*, Murchison, highly magnified. Coll. Geol. Survey Scotland.

Fig. 2. *Sp. carbonarius*, var. *Hibberti*, R. Eth., highly magnified. Coll. Geol. Survey Scotland.

Fig. 3. *Serpulites carbonarius*, M'Coy, nat. size. Coll. Mr. John Henderson, Woodhall, Water of Leith.

Figs. 4–6. *Discina nitida*, Phillips, nat. size. Two dorsal and one ventral valve. Woodhall, Water of Leith, near Edinburgh.

Fig. 7. *Lingula squamiformis*, Phillips, nat. size. Coll. Mr. John Henderson, Dean Bridge, Water of Leith, near Edinburgh.

Fig. 8. *L. squamiformis*, Phill.?, natural size. Coll. Mr. John Henderson, Craiglockhart Quarry, near Edinburgh.

Figs. 9, 10. *L. mytiloides*, Sowerby, near the nat. size. Coll. Mr. J. Henderson, Craiglockhart and Woodhall.

Fig. 11. *Avicula Hendersoni*, R. Eth., Jun., twice the nat. size. Coll. Mr. J. Henderson, Craiglockhart-Hill Quarry.

Figs. 12, 13 (and 14?). *Anthracoptera? obesa*, R. Eth., Jun., nat. size.
Figs. 12, 13. Casts in micaceous sandstone, Drumsheugh.
Fig. 14. Compressed and flattened individual in altered shale, Corstorphine Hill. Coll. Mr. J. Henderson.

Figs. 15–17. *Myalina sublamellosa*, R. Eth., Jun., nat. size. Coll. Mr. John Henderson, Craiglockhart Hill Quarry, near Edinburgh.

Fig. 18. *Nuculana Sharmani*, R. Eth., twice Jun., nat. size. Woodhall, Water of Leith, near Edinburgh.

Fig. 19. *Schizodus Salteri*, R. Eth., Jun., nat. size. Coll. Mr. J. Henderson; Drumsheugh, near Dean Bridge, Edinburgh.

Fig. 20. *Anthracosia? nucleus*, Brown?, nat. size; a poor and bad specimen. Coll. Mr. J. Henderson, Craiglockhart-Hill Quarry, near Edinburgh.

Figs. 22, 23 (and 21?). *Pandora? typica*, R. Eth., Jun., natural size.
Fig. 21. Drumsheugh. Coll. Mr. Gall. Shell crushed anteriorly.
Fig. 22. Drumsheugh. Coll. Mr. J. Henderson.
Fig. 23. Young form, Woodhall, water of Leith. Coll. Mr. J. Henderson.

Figs. 24, 25. Two small bivalves, undetermined casts.
Fig. 24. Twice nat. size. Drumsheugh. Coll. Mr. Gall.
Fig. 25. About twice the nat. size. Water of Leith. Coll. Mr. J. Henderson.

Fig. 26. *Littorina? scoto-burdigalensis*, R. Eth., Jun., much enlarged. Drumsheugh, near Dean Bridge, Edinburgh. Coll. Mr. Gall.

Fig. 27. The same, enlarged. Water of Leith. Coll. Mr. J. Henderson.

Fig. 28. *Pleurotomaria monilifera*, Phillips?, nat. size. Woodhall, Water of Leith. Coll. Mr. J. Henderson.

Fig. 29. *Murchisonia striatula*, De Koninck?, enlarged. Woodhall. Coll. Mr. J. Henderson.

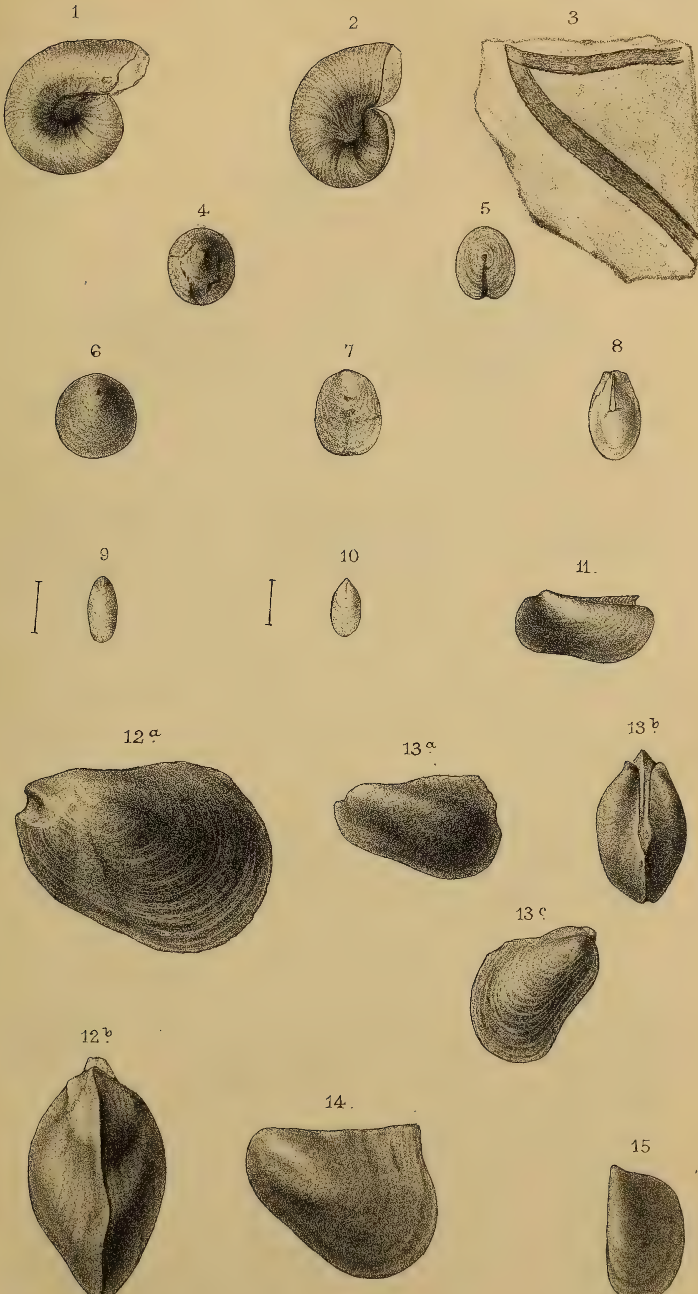
Fig. 30. *Bellerophon decussatus*, Flem., var. *undatus*, R. Eth., Jun., nat. size. Woodhall. Coll. Mr. J. Henderson.

Figs. 31, 32. *Nautilus cariniferus*, J. De C. Sowerby?, nat. size. Woodhall. Coll. Mr. J. Henderson.

Fig. 33. *Orthoceras*, sp. ind., nat. size, with incrusting coral. Woodhall. Coll. Mr. J. Henderson.

Fig. 33 *a*. *Chætetes*, sp. ind., fragment enlarged from fig. 33.

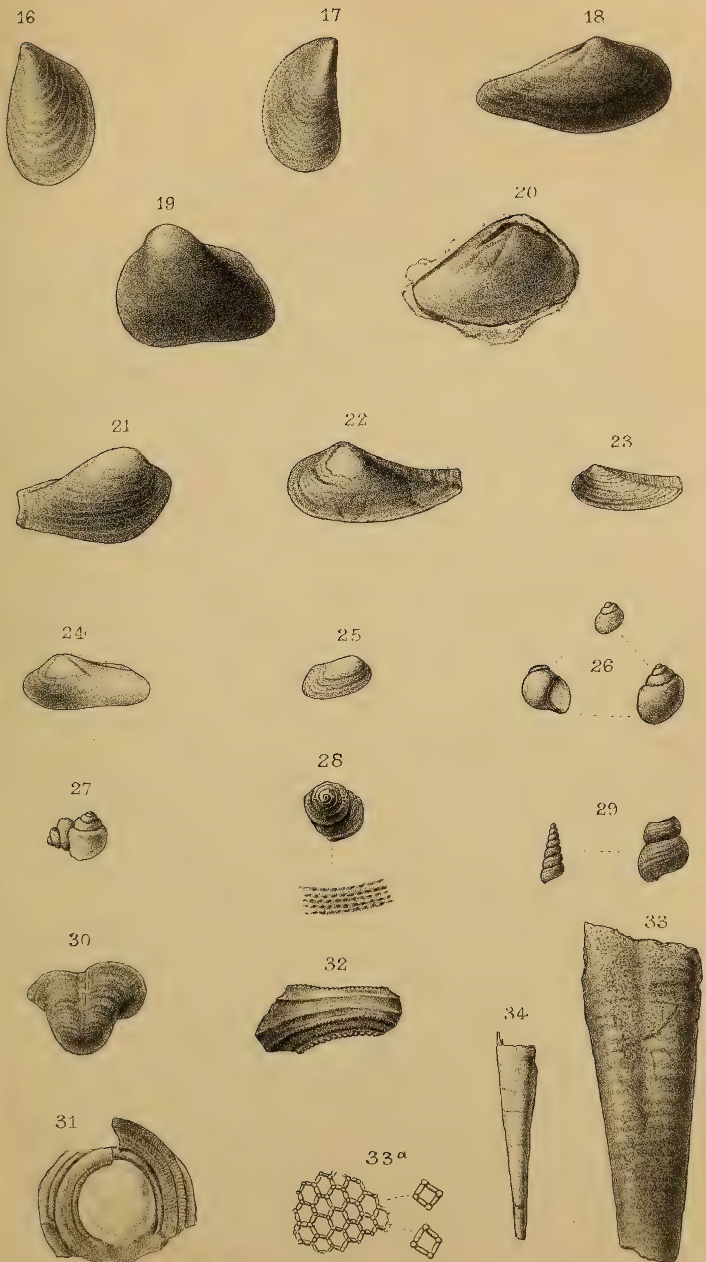
Fig. 34. *Orthoceras*, sp. ind., nat. size. Woodhall. Coll. Mr. J. Henderson.



G. Sharman del, C.L. Griesbach lith.

Mintern Bros. imp.

LOWER CARBONIFEROUS INVERTEBRATA.



G. Sharman del, C. L. Griesbach lith.

Mintern Bros. imp.

LOWER CARBONIFEROUS INVERTEBRATA.

2. DISCOVERY *of* SILURIAN BEDS *in* TEESDALE. By W. GUNN, Esq., F.G.S., of H.M. Geol. Survey, and C. T. CLOUGH, Esq., B.A., F.G.S., of H.M. Geol. Survey. (Read June 20, 1877.)

(Communicated by permission of the Director-General of the Geological Survey of the United Kingdom.)

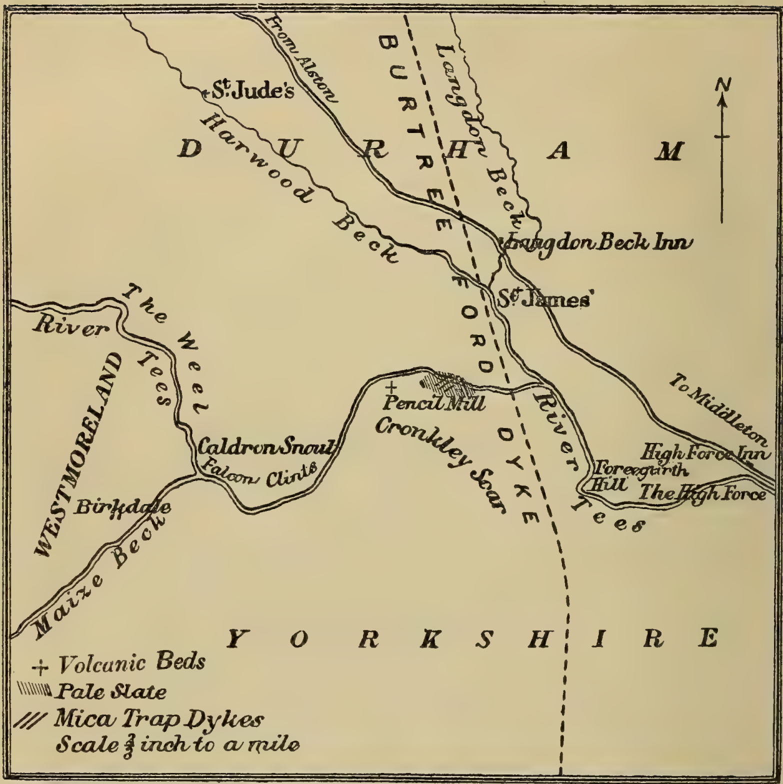
OUR colleague Mr. J. R. Dakyns, a few months back, put the question to geologists, "Is there a base to the Carboniferous rocks in Teesdale?" (Geol. Mag., Decade ii. vol. iv. p. 58), and briefly mentioned the reasons which had induced him to ask the question. Some time previously to the visit of Mr. Dakyns to Teesdale mentioned in the article referred to, Mr. Howell, of the Geological Survey, had made the same suggestion to one of us.

We have already, in the Geol. Mag. (*tom. cit.* p. 139), stated that there is no doubt that this suggestion is correct. In the present paper we offer to the Society the detailed proofs of this.

It will be advisable in the first place to say something about the physical structure of the dale, in order that the mode of occurrence of the older beds may be better understood.

It is generally well known in the dale that there is a great disturbance, going by the name of the Burtreeford Dyke (from Burtreeford, in Weardale, where the disturbance is well seen), entering the dale near Langdon Head and running diagonally across it roughly from north to south, and that this disturbance lifts the beds up to the west very considerably. As far as we have been able to make out in this district, the dyke does not appear to consist so much of an actual break as of a *sharp run-up* of the beds, with possibly local breaks here and there as well. The total displacement caused by this disturbance is sometimes thought to be indicated by the difference in height, about 350 feet, between the Whin Scars of Cronkley Fell on the west of the dyke and the Whin Scars of Forcegarth Hill on the east of the dyke. But it is not safe to assume that the Whin Sill behaves as a regular sill, and occurs everywhere on the same geological horizon; and in this case especially the assumption would lead one very far astray. We have been able to make out that between Forcegarth Hill and Cronkley Fell the whin has changed its position very greatly, that the whin of Forcegarth Hill occurs about the horizon of the Single-Post Limestone of Westgarth Forster's section, and that on Cronkley Fell it is on the horizon of the Rundle or Melmerby-Scar Limestone, which in this district may be taken as being about 400 feet below the Single Post; so that it is evident that the displacement caused by the dyke is not at all completely indicated by the difference in height of the Cronkley and Forcegarth-Whin Scars; for to this difference must be added the 400 feet of beds which come in between the two limestones in question.

Sketch Map showing the position of Silurian Beds in Teesdale.



It is by this great disturbance that the lowest beds which are seen in the Dale are brought up. These lowest beds are to be found near the old Pencil Mill at Cronkley, and they are exposed along the river-side for a length of nearly 700 yards. Probably, if the thick riggs of Boulder-clay which cover up so much of the low ground about here could be removed, the beds would be seen to occupy a much larger area. We have indicated in the above sketch map where these beds are to be seen, and the probable line of the Burtreeford Dyke.

These Pencil-mill beds consist of soft shales which were formerly worked up into slate-pencils at the Old Mill. Their general tint is a grey or greenish grey; but sometimes they are of a more decided light yellowish green, and sometimes of a purplish red colour. They are very homogeneous in character, fine in texture, and with apparently no definite bands of a hard or gritty character, such as would enable one to make out any distinct bedding. The shale is much laminated in places, and crossed by several sets of divisional planes; but the most prominent set, striking nearly east and west, looks like cleavage. Much of the mass is greatly cut up by quartz veins, and has a very crushed and disturbed appearance, giving one the idea that the dip is far from constant in direction or amount—that the beds are, in fact, much contorted. In places the laminæ of soft shale are seen to be crossed in various directions by dark grey or blackish bands, which, if they at all indicate the bedding, show that the above idea is correct. Even if we suppose that the beds are horizontal, there must be at least a thickness of 65 or 70 feet. Considerable time has been spent in searching for organic remains, but hitherto without result.

Several igneous dykes, four at least, pass through this bed. The most westerly of these is seen very clearly crossing the river in an E.N.E. direction, with a width of about ten yards and a southerly hade of 50° from the horizontal. Two others have a similar direction and hade, but are somewhat narrower. The direction of the most easterly dyke is rather uncertain, but appears to be about S.E. by E.

Our colleague Mr. F. Rutley has examined for us several specimens of these dykes (which do not vary much in character); and he gives the following description of one of them :—

" In a microscopic section of this rock mica crystals (magnesium mica?), in part decomposed into a yellowish-white substance, are seen in considerable quantity. Crystals of apatite, decomposed garnets, patches of pyrites, and some small rhombohedral crystals which are probably siderite, are also present. The last-named crystals, although sometimes irregularly distributed, are sometimes aggregated in strings, or along minute fissures. In this section some of the clearly discernible crystals of felspar exhibit triclinic banding. The rock seems to be intermediate between minette and kersanton."

It has long been evident to the dalesmen that this Pencil-mill bed is not simple unaltered Carboniferous shale; and two general theories have prevailed as to what it is. Both of these assume it to be Carboniferous shale, but altered: the one supposes the alteration to have been effected by the Whin Sill; the other that the alteration was effected by the dykes there seen, and that these dykes have some connexion with whin which is now and then seen occurring roughly along the line of the Burtreeford Dyke.

The first of these theories is at once seen to be untenable, owing to the great vertical distance between the base of the whin on Cronkley Scar and the top of the Pencil-bed, which is about 165 feet; and it is in this district beyond parallel for the metamorphism effected by the Whin Sill to extend to any thing like so great a distance. At the High Force the limestone at the bottom of the section is only 20 feet below the whin-base, and yet it shows no certain sign of any alteration.

Neither is the second theory satisfactory. In the first place, the general line of the Burtreeford Dyke probably passes several hundred yards to the east, and all the igneous rocks which are seen in connexion with the Burtreeford Dyke are totally different in character from those of the Pencil-mill. We shall, moreover, subsequently adduce reasons to show that the Pencil-mill dykes have effected little or no change in the surrounding beds.

Thus it has been necessary to reject the above two theories. We are, in fact, obliged to conclude that the Pencil-mill bed is not Carboniferous at all. Below we give the main considerations which have led us to this conclusion :—

(*a*) *Character of the Bed.*—A comparison of this pencil-bed with various other pencil-beds which are known to be merely Carboniferous shale altered by proximity to whin shows a great difference between them. Even in hand specimens the difference is usually well marked; we do not know of any approach in altered Carboniferous shales to the extremely fine and homogeneous texture of this bed, nor to the greenish grey or purple-red tint which sometimes prevails in it. Probably on this evidence alone any one who had been well acquainted both with altered Carboniferous shale and with the various Silurian shales would have been led to suspect that the bed was not Carboniferous. More than a year ago a specimen of it was sent to the Rev. T. G. Bonney; and he remarked that it had a wonderful resemblance to some of the Silurian shales. On the other hand, there can be no doubt about its great resemblance to the Pale Slates or Stockdale Shales that are seen to overlie the Coniston Limestone in the neighbourhood of Dufton. Mr. W. T. Aveline, who came to examine this bed, pronounced at once in favour of its being of Silurian age, and thought it most resembled the Pale Slates.

(*b*) *The Character of the Dykes.*—No mica-trap dykes are known in the Carboniferous beds of this district, or of any part of the north of England, while such dykes are common in the Silurian districts of the Lake-country (*vide* Geol. Survey Memoir on Quarter Sheet 98 N.E., pp. 16, 17).

(*c*) *Beds not altered by the Dykes.*—All the evidence attainable tends to show that it is not the dykes which traverse the bed that have altered it. The bed can be traced 230 yards from the nearest visible dyke; and probably the nearest point that a dyke passes through cannot be less than 130 yards from this place; and yet here the bed has just the same character that it has close to the dykes. Surely, however great the altering power of these dykes might be, we should expect at this distance to find some decrease in this alteration. Moreover the dykes of this kind which occur in the Lake-country do not usually effect much alteration in the surrounding beds. (Geol. Survey Memoir on Quarter Sheet 98 S.E. p. 42.)

(*d*) *Character of the Veins.*—In this district, veins when passing through Carboniferous shales are generally mainly filled with what the miners call "douk," soft dark clay evidently formed from the shale on either side of the vein. Now, as we have said, there are very many veins cutting through the pencil-bed, and the vein-stuff in them consists chiefly of quartz. There is, indeed, besides quartz, usually something corresponding to "douk;" but the quartz is by far the most prominent element. In places, ribs of quartz 8 or 9 inches thick may be found; and thinner ribs abound on all sides. Our colleague Mr. J. G. Goodchild informs us that the number of quartz veins is quite a characteristic feature in the Silurian shales under Cross Fell, when compared with Carboniferous shales in the same country. This difference has also been noted by Prof. Phillips (Geol. Yorksh. part ii. p. 4).

(*e*) *Apparent Unconformity between this bed and the Carboniferous beds above.*—The next beds seen on the banks of the Tees higher up the river than the Pencil-bed occur under the Whin Sill at Falcon Clints. The section here is described at length by Sedgwick in his paper on the "Geology of High Teesdale" (Cambr. Phil. Trans. 1824, vol. ii. p. 174), and is alluded to by Phillips (Geology of Yorkshire, pt. ii. p. 78). Phillips was struck by the resemblance of the beds to the basement Carboniferous beds in Ribblesdale; among other things, he says:—"A few seeming beds occur of a quartzose compound almost exactly like grauwacke, and closely resembling some local beds which cover the slate deposit in Ribblesdale." The lowest bed seen here, appearing just above the Tees, is a conglomerate made up mainly of quartz and clay-slate pebbles of a subangular character, the larger pebbles being sometimes several inches in length. Somewhat similar conglomerates can, however, be seen nearer the Pencil-mill than this, and in equally distinct exposures. Some time ago we had an open cut made in the bank above and a little to the west of the Pencil-mill, in order to discover, if possible, the upper limit of the Pencil-bed, and we succeeded in finding it readily. In this cut we have exposed at the bottom the Pencil-bed of exactly the same character as at the Mill, and resting upon it 5 feet of breccia composed of angular fragments of shale like that it is resting upon; for the next 8 feet we get alternations of quartzose conglomerates, more or less coarse, and mostly hard, but with some finer and softer sandstones. Above this the section is obscure. The next 17 feet appear to be made up of shales and more or less shaly conglomerates.

We wish to call special attention to the fact that in this open cut the Pencil-bed is of exactly the same character as at the Mill: specimens from either locality being placed before you, it would be impossible to say which specimen came from which locality, while the conglomerate beds are not altered at all. It is true that beds composed of coarser material seldom or never do show cleavage so well as finer beds, shale &c.; but in these conglomerates, whether coarse or fine, there is never the slightest approach to cleavage, nor do they show any sign of any other alteration such as ordinarily takes place in the neighbourhood of whin dykes &c. The finer-sandstone beds interbedded with the conglomerates have nothing approaching the character of quartzites; and the more shaly bands are like simple unaltered Carboniferous shale.

As far as the evidence goes, too, there would appear to be a difference in dip between these Pencil-mill beds and the Carboniferous rocks of the neighbourhood. We have already stated that the true dip of the beds cannot be precisely determined, but that it appears to be at high angles and in various directions. Now the higher Carboniferous beds in the neighbourhood are either lying horizontally, or else, under the influence of the Burtreeford Dyke, they are dipping steeply and uniformly to the E.N.E.; and the conglomerates &c. resting on the Pencil-beds are lying horizontally.

We have now given the main points that occur to us as being likely to help to settle the question. We think that, taken altogether, they form a mass of cumulative evidence which is overwhelming.

Taking, then, our conclusion as proved, we proceed to mention, very briefly, a point in which this discovery is of great theoretical interest.

From the bottom of the Whin Sill on Cronkley Scar to the top of the Pencil-bed there is a vertical distance of 165 feet. The beds occurring in this space are probably somewhat as below, in descending order:—

	feet	
Limestone	100	In places very impure, sandy and shaly bands coming in and dying out very irregularly. Probably in the lower 50 feet the limestone bands are subordinate to the sandy and shaly bands.
Conglomerates.........	65	With quartz and clay-slate pebbles.

We cannot give the section as very trustworthy in respect of details, because the lower portion of Cronkley Scar is so covered by tumbled whin that the lower beds are very rarely to be seen; but, judging by better sections to be seen on either hand, it is probable that it is roughly correct. There can be no doubt that the limestone in the section must represent in part the Melmerby-Scar Limestone of the Pennine escarpment. Now in this escarpment we have beneath this limestone an enormous thickness of Carboniferous beds. At Roman Fell, about eight miles from the Pencil-mill in a S.S.W. direction, these Lower Carboniferous beds are no less than 1500 feet thick, according to our colleague Mr. Goodchild.

The two sections we have here brought together for comparison must be taken as really representing the different developments of the Lower Carboniferous beds in the two districts. It is impossible to explain away the difference by supposing that in Teesdale the Pencil-bed is caught in between two enormous faults or any thing of that kind, and this for two reasons: in the first place, as has been said, conglomerate beds can be seen resting directly on the Pencil-bed; in the second place, the sections on the Fell-sides around are too good to allow of any such faults having escaped our observation.

And with this difference in the beds below the Melmerby-Scar Limestone, the differences in the Melmerby Scar-Limestone itself agree. About Brough this limestone is several hundred feet thick, and near the Pencil-mill it would appear to be considerably less; moreover it is not, in this last locality, at all a pure limestone. It contains, as we have already indicated by the section under the whin at Cronkley, many irregular beds of shale.

In the sketch map (p. 28) we have only put in these Pencil-mill beds where they are actually to be seen. The great quantity of boulder-clay about would be enough to justify one in this resolution; but, besides this, we have, of course, to consider the possibility or, rather, probability of changes in the development of the Carboniferous basement-beds. We may state, however, that there is a considerable stretch of flat low-lying land in the corner between Harwood Beck and the Tees, and that these new-found Silurians probably occur over an area out of all proportion to their actual exposure. It would be unnatural to suppose that the whole of this flat area is occupied by beds like those at the Pencil-mill. The Stockdale Shales, which these beds so closely resemble, are usually only several hundred feet thick; and supposing that these old beds are dipping in Teesdale at any thing like as high an angle as they usually are in the north of England, we should soon get over this thickness and pass on to higher or lower beds. And, indeed, there are positive indications that the whole of this area is not occupied by the Pencil-mill beds. Here and there along the sides of the Tees, in the neighbourhood of the Old Mill, loose fragments are found which cannot be referred to any known Carboniferous rock of the neighbourhood, nor to the Pencil-mill bed itself. Some of these pieces appear very like the passage-beds which occur between the Stockdale Shales and the Coniston flags; they are generally hard dark mudstones with occasional grey gritty bands. There are pieces something like these to be found in the Conglomerate beds which have been described; and possibly some of them may have been derived thence; but others are much larger than any thing seen in the Conglomerates, and it is not likely that they have come from them.

If we exclude this source of supply, there are only two others whence we may suppose them to have been derived. They must either have come from a near spot in Teesdale, and be now not far out of place, or they must have come as drift-boulders over from the west country. Now this last supposition is untenable. It is quite true that thousands of Shap-granite boulders and other west-country rocks have crossed over the Pennine Chain by way of Lunedale Head and Stainmoor; but the higher Fells just to the north seem to have formed an impassable barrier to the invaders. As far as our present evidence goes, it would seem clear that nothing at all ever came over into High Teesdale by way of Scordale, High Cup Nick, and the higher passes to the north of these. No boulders certainly known to be foreign have been found in the Dale above Middleton; and the loose pieces in question only occur in the neighbourhood of the Pencil-mill; they have not been found in the Tees above Widdy Bank.

Besides these boulders, there are others which closely resemble the impurer bands in the Coniston-limestone series; but nothing can be said positively about these.

Note.—Since the above was written, beds belonging to the volcanic series of the Lake country have been found in place on the Yorkshire side of the Tees, opposite Widdybank Farm. Their presence in the dale had been previously inferred from boulders.

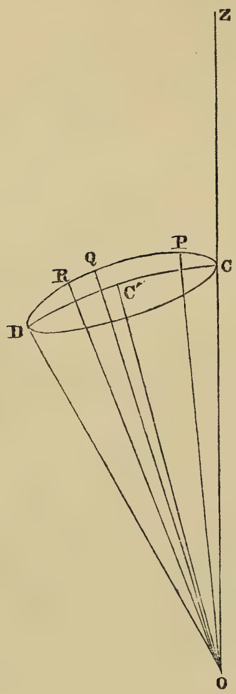
3. *On* POSSIBLE DISPLACEMENTS *of the* EARTH'S AXIS OF FIGURE *produced by* ELEVATIONS *and* DEPRESSIONS *of her* SURFACE. By the Rev. J. F. TWISDEN, M.A., Professor of Mathematics in the Staff College. Communicated by JOHN EVANS, Esq., F.R.S., V.P.G.S. (Read February 21st, 1877.)

1. IN the Anniversary Address delivered to the Geological Society on the 18th February 1876, by its President, J. Evans, Esq., the following passage occurs (p. 62):—"Taking our globe with the distribution of land and water as at present existing, I should like to inquire of mathematicians what would be the theoretical result of such a slight modification, geologically speaking, as the following:—Assume an elevation to the extent, on an average, of 4000 feet over the northern part of Africa, the centre of the elevation being, say, in 20° north latitude. Assume that this elevation forms only a portion of a belt around the whole globe, inclined to the equator at an angle of 20°, and having its most northerly point in the longitude of Greenwich, and cutting the equator at 90° of east and west longitude. Assume that along this belt the sea-bottom and what little land besides Africa it would traverse were raised 4000 feet above its present level over a tract 20° in width. Assume further that the elevation of this belt was accompanied by corresponding depression on either side of it, so as to leave the total volume of the mineral portion of the earth unaffected. Would not such a modification of form bring the axis of figure about 15° or 20° south of the present, and on the meridian of Greenwich—that is to say, midway between Greenland and Spitzbergen? and would not, eventually, the axis of rotation correspond in position with the axis of figure?"

2. The question whether there has been in past ages a considerable change in the geographical position of the earth's axis of revolution, is said to be one that presents points of great interest to geologists. Whether this be so or not, the above extract has the merit of putting the question into a distinct form, in which it admits of a precise answer. The investigation of which an outline is given in the following pages was undertaken with a view to answering the question as put in the above extract; it also throws some light on the question of the amount of elevation and depression needed to effect a considerable change in the position of the earth's axis of maximum moment of inertia, or axis of figure. It may be observed that the forces by which the elevations and depressions are effected do not come under discussion.

3. The method of representing the motion of a rigid body about its centre of gravity by means of the momental ellipsoid and the invariable plane is well known. For the purpose of the present question it will be enough to mention a simpler construction, which will represent the motion with sufficient accuracy. It is known that at present the

earth's axis of rotation coincides sensibly with the axis of figure. In the diagram suppose that O is the centre, and O C the axis



about which the earth is at any instant revolving; and let us suppose that in consequence of elevations and depressions the axis of figure is shifted into the position O C′, C′ being on the surface of the earth. With centre C′ and radius C′C describe the small circle C P Q R D. The lines which join points in the circumference of this circle to O will be successively axes of the earth's rotation; and when any one of them is actually the axis of rotation, it will come into a position nearly coinciding with the original direction of OC, *i. e.* with O*z*, which continues nearly fixed in space. Thus OP, OQ, OR, OD will come successively into a position nearly coinciding with O*z*, and when there will be at that instant the axis of rotation. If COC′ were an angle of 20° there would be a small diurnal variation in the direction of O*z*; but the main effect would be to bring OD round into coincidence with O*z*, *i. e.* to bring a point in latitude 50° N. up to the north pole, and then to bring it round again to its original position. This interchange of positions would go on continuously, the point D returning to its original position after an interval of about 300 days.

It is plain therefore that the question before us will be answered if we determine the position of the earth's axis of figure after the elevations and depressions have been effected; *i. e.* we need do no more than determine the angle C O C′. In doing this it appears that approximate formulæ and numbers will answer every useful purpose.

4. If A, B, C, denote the moments of inertia of the earth about principal axes through her centre of gravity, it is known that (approximately) A=B and 300 (C—A)=C. It will be assumed that C – A equals

$$\frac{1}{300} \cdot \frac{16}{15} \pi \rho a^5, \qquad (1)$$

where ρ denotes the average density of rocks at the surface*, a the equatorial radius, and π the number 3·14159.

5. The steps in the requisite calculation may be briefly indicated as follows:—

(*a*) The moments and products of inertia are found with respect to the earth's principal axes of a zone passing round the earth of small uniform height (h) enclosed between two parallel planes inclined at an angle α to the equator, and at assigned perpendicular distances from the centre; for the purpose of this determination it appears that the ellipticity of the earth may be neglected.

(*b*) In applying these formulæ to the case suggested in the extract (art. 1), the width of the elevated zone is assumed to be 23° 6′, for convenience (the sine of half this angle being 0·2); it is also assumed that the submerged parts of the elevation produce the same effect as if they were above water, and the depressions as if they were empty; it is also assumed that the matter removed to form the depressions is transferred to form the elevation: all these assumptions are favourable to the effect contemplated in the extract. The result arrived at is, that the moments of inertia A, B, C′ become respectively,

$$A + \tfrac{1}{25} ma^2 (2-3\cos^2 \alpha),$$
$$B - \tfrac{1}{25} ma^2,$$
$$C + \tfrac{1}{25} ma^2 (2-3\sin^2 \alpha),$$

and that the axes with reference to which A and C are taken are no longer principal axes, because there is a product of inertia (Σmzx) equal to $\frac{3}{25} ma^2 \sin\alpha\cos\alpha$, where m denotes the mass of the elevation.

(*c*) If now θ is taken to denote the displacement of the axis of figure (COC′), it is easily shown that

$$\tan 2\theta = \frac{3ma^2 \sin 2\alpha}{25\,(C-A) + 3ma^2 \cos 2\alpha}.$$

* The expression for C – A is deduced from the suppositions usually made in treatises on the figure of the earth (Airy's Treatise, p. 189).

6. In applying this formula to the question proposed in art. 1 we observe that θ will have nearly its largest value when α is 45°; we will therefore take this value instead of 20° for the obliquity of the belt, and we will take the height of the elevation to be h; we then plainly get

$$\tan 2\theta = \frac{27h}{a}; \quad \ldots\ldots\ldots\ldots \quad (2)$$

or, if we take h to be $\frac{4}{5}$ of a mile, θ is an angle of about 9′ 17″. The answer to the question is, therefore, that the axis of figure would be displaced through an angle of less than one sixth of a degree, and the displacement would take place, not on the meridian of Greenwich, but on its prolongation, *i. e.* on the meridian of a station in long. 180°. It is plain from equation (2) that, to produce a displacement of as much as 1°, h (the height of the elevation) would have to be more than 5 miles.

7. These results seem conclusive in regard to the particular method of elevation suggested in the extract. But the question may be fairly asked whether elevations and depressions of some other kind might not produce the desired displacement? If any particular kind of elevation or depression is suggested, it can be treated by a method resembling that already employed; but when the question is asked in a general form, of course a specific answer is not possible; still some general results may be arrived at which ought at least to be borne in mind by those who speculate on this subject.

8. Let us suppose the axes of z and x to be those with reference to which C and A are taken; then, if we assume that a mass of matter (m) is transferred in the plane of zx from a point whose coordinates are (z, x) to a point whose coordinates are (z', x'), it is easily shown that the displacement of the axis of figure (θ) is given approximately by the formula

$$\tan 2\theta = \frac{2m(z'x' - zx)}{\mathrm{C} - \mathrm{A}}; \quad \ldots\ldots\ldots\ldots \quad (3)$$

so long as the matter moved is but a fractional part of the whole equatorial bulge, we may safely reason on this formula.

9. Now, if the matter is transferred from one point to a neighbouring point, $z'x'$ will not differ much from zx, and consequently $\tan 2\theta$, and therefore θ, will be but small. This result is important and is general: *e. g.* matter transferred from a mountain-range into a neighbouring sea, molten matter transferred from an underground region to a neighbouring region above or below ground would produce but little effect on the earth's axis of figure, even if the whole amount of matter transferred were large.

10. Again if we suppose the matter to be transferred from latitude ϕ to latitude ϕ', we may write the equation (3) as follows,

$$(\mathrm{C} - \mathrm{A}) \tan 2\theta = 2ma^2 \sin(\phi' - \phi) \cos(\phi' + \phi), \quad \ldots \quad (4)$$

with sufficient accuracy for present purposes. If this equation gives

θ a positive value, the pole is shifted in the prolongation of the meridian on which the transfer takes place*.

11. From this formula we can draw several conclusions, of which we may specify the following:—If the latitudes are one north and the other south, the effect is considerable relatively to the amount of matter moved, and is greatest when the transfer is from 45° N. to 45° S. (or *vice versâ*); and then the right-hand side of equation (4) is $2ma^2$†.

12. This conclusion is of great importance. If we suppose many masses removed, the numerator of the fraction in equation (3) will merely be the sum of their individual effects; and as they cannot all be moved from lat. 45° N. to lat. 45° S., their total effect cannot be so great as it would be if they were all concentrated in a point and transferred from lat. 45° N. to lat. 45° S.; and consequently, if μ is the whole mass moved, the effect of the transfer on the position

* With a view to certain statements in the postscript, it may be well to give, in the form of rules, some of the results that follow from the above formula, in cases where matter is transferred from one point to another along a given meridian:—

(*a*) If the matter is transferred from a point short of 45° S. to any point in north latitude, the displacement of the north pole is in the prologation of the meridian; *i. e.* it takes place on the meridian whose longitude exceeds that of the given meridian by 180°.
(*b*) If matter is transferred from a point in north latitude to a point to the south but still in north latitude, the displacement of the north pole will be as in the last rule (*a*), provided the sum of the two latitudes exceeds 90°.
(*c*) But in the last rule (*b*), if the sum of the latitudes is less than 90°, the displacement of the north pole will be on the meridian, and not on its prolongation.
(*d*) If matter is transferred from a point in north latitude to a point further to the north, and if the sum of the latitudes exceeds 90°, the displacement of the north pole is on the meridian, as in (*c*).

It may be well to add that, if we suppose matter to be transferred along a parallel of latitude, the displacement of the pole is given by the formula

$$\theta\,(C-A)=2ma^2 \sin 2L \sin \tfrac{1}{2}l,$$

where L denotes the latitude, and l the difference between the longitudes of the points from and to which the transfer takes place. The displacement of the pole (north pole if the latitude be north) is on the great circle at right angles to the meridian, midway between the points from and to which the transfer takes place, and in a direction opposite to that of the transfer. Hence we may state the following rule:—

(*e*) If the longitude of the middle point of the space over which the transfer takes place is λ E., then, if the transfer takes place from west to east in the northern hemisphere, the displacement of the pole is on the meridian of $\lambda-90°$ E.; *e. g.* the tendency of the denudation caused by the Thames, whatever its amount, is to displace the pole on the meridian of $-90°$ E., or 90° W., *i. e.* towards the north coast of America.

† It follows from the formula in the last note that, if matter is transferred along a parallel of latitude, the greatest effect is produced when the transfer is in latitude 45° N. or S., and through a difference of longitude of 180°; and then the effect is the same as that stated in the text in the case of transfer from 45° N. to 45° S.

of the axis of figure cannot be so great as the value of θ given by the equation

$$\tan 2\theta = \frac{2\mu a^2}{C - A};$$

and, further, if we suppose the whole amount of matter in the equatorial bulge to be denoted by M, this equation, combined with equation (1), will give

$$5\mu = M \tan 2\theta.$$

If, now, θ is an angle of 20°, μ must be rather more than a sixth part of the equatorial bulge—a quantity of matter which would cover the whole of the torrid zone on both sides of the equator—and have a thickness of more than $3\frac{1}{2}$ miles. In whatever way this enormous amount of matter were transferred from one part of the earth to another, it could not shift the axis of figure through an angle of 20°. It is to be particularly observed that the transfer of matter might take place in such a way as to produce no effect of the kind contemplated; or, again, it might be made in such a way as to produce but little effect, or, indeed, any effect, up to a point short of 20°. Within that limit the effect would depend on whence the matter was taken, and where it was placed. If, for instance, the elevations and depressions in the zones considered in art. 6 had been on such a scale that the quantity of matter transferred had been a sixth part of the equatorial bulge, the axis of figure would be displaced through no more than an angle of about 1° 30′.

13. If we suppose the axis of figure by any means to be brought to an inclination of several degrees (say 20°) with the axis of revolution, results would follow which it may be just worth while to mention. Referring to the figure, suppose that CD is the meridian of Greenwich; then D will be a point in latitude 50° N. If we suppose the earth on a given day to be revolving, in these altered circumstances, round OC, about a hundred and fifty days after OD will come into a position very near to Oz, and will then be the axis of rotation. Supposing the earth rigid, its form would undergo no change; but in the one case the minor axis of the ocean-surface would coincide with OC, and about 150 days after it would coincide with OD. The effect which this would tend to produce can be readily ascertained by supposing two ellipsoids of revolution, shaped like the earth, and of the same size, to have coincident centres, and their axes of revolution to be inclined at an angle of 40°. It would be found that at certain points one of the ellipsoids would have its surface 8 miles above, and at other points 8 miles below the surface of the other ellipsoid. In other words, the effect would be to cause in the ocean a huge tidal motion with a period of about 300 days. The various effects which such a tide would produce would be highly complicated; but it may be pretty confidently asserted that one of the effects produced would be that the ocean would sweep over the earth and render it quite uninhabitable.

14. The conclusions to which the investigation leads may then be summed up thus :—

(1) That the displacement of the earth's axis of figure from the axis of rotation that would be effected by the elevations and depressions of the kind suggested would be less than 10′ of angle.

(2) That a displacement of as much as 10° or 15° could be effected by elevations and depressions of the kind suggested only if their heights and depths exceeded by many times the heights of the highest mountains.

(3) That under no circumstances could a displacement of 20° be effected by a transfer of matter of less amount than about a sixth part of the whole equatorial bulge.

(4) That even if a transfer of this enormous amount of matter were to take place, it would not of necessity produce any effect, and might only produce a small effect on the position of the axis of figure.

(5) That if by any means a considerable deviation were effected of the axis of figure from the axis of rotation, enormous tidal motions of the ocean would be produced, and its waters would sweep over the continents much as a rising tide sweeps over a low bank on a level shore.

Postscript.

15. It will be observed that in the extract (p.35) it is suggested that the earth's axis of figure deviates in the first place by 15° or 20° from the axis of rotation, and that then the two axes eventually come into coincidence. It may be well, with a view to rendering the discussion more complete, to add a few remarks on this point.

16. In the case of a rigid body turning round an axis not coinciding with the axis of figure there is no tendency, so far as the mere fact of rotation goes, to bring the two axes together. Thus, in the diagram, the half angle of the cone ($C'Oz$) would continue constant when the separation of the axes had once been effected, unless external forces were brought to bear upon the body. Undoubtedly cases might be specified in which the final result of the long-continued action of comparatively small forces would be to continually diminish the angle $C'Oz$, and at length cause the rotation to take place round the axis of figure in its new position within the body *. Assuming that such forces, though very slow in their operation, are actually called into play in the case of the earth, it might, of course, follow that, if the axis of figure of the earth were slowly displaced from its present position, the axis of rotation would follow it, and thus, though the two would never get far apart, a considerable geographical displacement might at length be effected in the position of the pole. Now the reasoning and the results arrived at in the above paper have a very direct bearing on this hypothesis; for it will be observed that they serve to determine the amount and direction of each of the small displacements; and the final position of the axis of figure and therefore, by hypothesis, of the axis of rotation, is the

* One such case is mentioned in Routh's 'Rigid Dynamics,' p. 432, 3rd ed.

total effect of all these displacements put together. The accumulation of these small displacements is therefore the only new point for discussion.

17. It may be assumed that, at present, and within the more recent geological periods, the earth is, in the main, a solid body*, the interior being intensely hot, but kept solid by the pressure of the superincumbent parts. This general statement is, of course, not inconsistent with there being tracts of molten matter at various places within the solid mass of the earth.

18. This being so, the notion of there being any considerable transfer of matter by change of place from one region to another below the surface may be dismissed without discussion. But what would be equivalent to such a transfer might arise from contraction due to internal cooling. If the contraction, however, were uniform throughout the mass of the earth no change would be produced in the position of the axis of figure. If the contraction were not uniform, there might be such a change; but it will be observed that contraction is a case of transfer of matter from one position to a neighbouring position, and consequently (art. 9) is not of a kind favourable for producing a large effect. If a considerable effect of the kind intended were produced by contraction, there would have to be an inequality of contraction on a very large scale.

19. In illustration of this point I may mention the results obtained in the following case:—Suppose a solid body of uniform density of the same size and shape as the earth, and consider an octant of its volume which has its curved surface in the northern hemisphere comprised between the equator and the meridians of 45° E. and 45° W. of Greenwich. Suppose that, the other parts of the solid continuing uncontracted, this solid octant undergoes a uniform contraction of volume which has the effect of lowering its surface by two miles below the general surface of the solid. This contraction would bring the axis of figure forward towards Greenwich by about 1° from its original position. This case will sufficiently illustrate the point that inequality of contraction would have to be on a very large scale to produce a considerable result of the kind contemplated. Whether any slow deformation of the earth could be effected on a large scale by unequal contraction in the process of cooling would depend, I suppose, on the kinds of matter composing the inner parts of the earth, and on their arrangement. In the absence of all information on these points the question hardly presents itself for serious discussion. The existence of inequality of contraction is purely hypothetical; and nothing is known of the circumstances which would render such an hypothesis probable or the reverse.

20. There remains for discussion the case of matter transferred on the surface of the earth by water. Here, at all events, we have a *vera causa*, a process actually in operation which might conceivably produce the desired effect. The question is whether there is any

* Proc. Roy. Soc. vol. xii. pp. 103, 104.

ground for believing that the effect has, in point of fact, been produced.

21. Now, if we have regard to the existing distribution of land and water, the first point that calls for attention is, that the joint effect of all the denudations at present in progress is not cumulative but residual. It is an effect resembling the resultant of a number of forces rather than their sum. In the case of some rivers their effects tend to concur; in the case of others they tend to neutralize each other; there are other cases in which the effects would be but small in proportion to the amount of denudation; and it may be added that concurrence or the reverse may take place in the effects produced by rivers very far apart. In illustration of these points I will apply the rules enunciated in the note to art. 10 to some of the great rivers, observing that I assume that the matter they transport is carried from the upper regions of the rivers to their deltas, a supposition sufficiently true for present purposes. The great rivers of Siberia tend to shift the north pole on a meridian of about 100° E. long. (rule *d*); the Mississippi tends to shift the north pole on a meridian in about 90° W. (rule *c*), *i. e.* on the prolongation of a meridian in about 90° E. The effects of the Mississippi therefore tend to neutralize those of the Siberian rivers. A case of concurrence is that of the Dnieper, Don, and Volga, on the one hand (rule *b*), with the Nile (rule *a*), on the other, their joint tendency being to displace the north pole on the prolongation of a meridian in about 40° E. long. In these cases the rivers flow on the whole from N. to S. or from S. to N. Another case of concurrence is that of the great rivers of China, which, on the whole, flow from west to east and have a mean longitude of about 110 E., so that their tendency is (rule *e*) to displace the north pole on the meridian of about 20° E.; consequently we have here also a case of neutralization; for the group formed by the great rivers of China, has a nearly opposite tendency to that of the group formed by the Dnieper, Don, and Volga on the one hand and the Nile on the other. As an instance of a denudation which tends to have but a small effect in comparison with its amount, we may take that produced by the Amazons, the course of which, running nearly along the equator, has little tendency to affect the position of the pole. Another case is that of the Indus, Ganges, and Bramaputra; they cannot be reckoned to transfer matter through more than about 10° of latitude; their tendency, however, is to increase the displacement produced by the Siberian rivers (rule *c*).

22. These cases are cited merely to illustrate the point that the joint effect of all the denudations going on at a given time is not a simple accumulation of small results, but is a residual or resultant effect of many separate tendencies which in a greater or less degree neutralize each other. To ascertain quantitatively what the total effect of all these tendencies is, the effects of matter transported by icebergs as well as by rivers would have to be taken into account, and the effects of small as well as of large rivers. For the solution of such a question the data do not, I believe, exist. But it is not unlikely that at present there is a predominating tendency to shift

the north pole in some one direction, possibly on a meridian in a longitude of about 90° E.

23. The next point to be considered is, that so long as a given distribution of land and water exists there will be no great change in the position of the earth's axis of figure, even supposing that so long as that distribution lasts the denudations do not produce effects which neutralize each other, but have on the whole a predominating tendency to shift the pole in some determinate direction.

24. It will be well to define what I mean by a given distribution of land and water. Take the land as it is at present, and suppose the process of denudation to go on, making amongst other changes such a change as this—that the whole continent of North America is removed bit by bit and formed into a new continent side by side with South America. By the time such a result has been brought about, it may, I think, be fairly reckoned that a new distribution of land and water has been effected. Now, while this change and the other contemporaneons changes are going on, let us suppose that their whole resultant effect on the position of the earth's axis of figure is represented by the effect produced by the removal of the North-American continent; *i.e.* the other tendencies neutralize each other, and leave this as the residual effect of the whole. On this supposition, taking the quantity of matter moved as a volume three miles thick with an area equal to $\frac{1}{27}$ of the area of the globe, and supposing the whole moved as a point from lat. 45° N. to 20° S., the north pole would be shifted through about three quarters of a degree during the continuance of this one distribution of land and water.

25. This reasoning leads directly to the following conclusion:—In order to produce by denudation such an effect as the geographical displacement of the pole through an angle of 15° or 20°, we must make several suppositions, thus:—(*a*) We must suppose that a large number of redistributions of land and water have been effected one after another, a redistribution being a change on a scale as large as I have endeavoured to indicate; (*b*) that during each of the epochs during which any one of the distributions has lasted there has been a prevailing tendency to shift the pole in one determinate direction; and, further, (*c*) that the prevailing tendencies throughout the successive distributions have been such as to add up and produce a large total, or, in other words, that they have not been such as to neutralize one another.

26. If, then, a great geographical displacement of the pole is to be effected by denudation, it becomes necessary to allow that geologists have at their disposal a considerable number, say ten, fifteen, or twenty consecutive distributions of land and water. If this be allowed, it may also be allowed that it is not improbable that during each of them severally there would be a prevailing tendency to shift the pole in some determinate direction. Each successive distribution of land and water would gradually change into that which succeeds it, and its prevailing tendency to shift the pole would insensibly change into that of its successor. It is very hard to imagine that these successive prevailing tendencies to move the pole should re-

main identical while the denudations which gave rise to them have undergone a complete change. In fact, unless there is some reason to believe that throughout the whole of these successive epochs there has been some predominating cause tending to accumulate, in some one particular direction, all this infinity of minute changes, there is no ground for believing that denudation is actually capable of producing the desired effect.

27. This conclusion seems to come out very plainly as the final result of the reasoning expounded in the present paper. It is not indeed an actual determinate answer like that which can be returned to the question in art. 1. But it is, perhaps, as distinct an answer as, all circumstances considered, could be fairly expected*.

Discussion.

Mr. Evans was willing to admit that in his Address he had somewhat overstated the amount of change in the position of the polar axis which was likely to result from the supposed belts of elevation and depression. When, however, he was told that the displacement would not exceed 10 miles, notwithstanding his implicit faith in mathematics, there arose an inward feeling of disbelief as to the conditions of the problem having been accurately stated in order to obtain such a result. It seemed to him that the author had treated the globe as an absolutely solid spheroid instead of a terraqueous globe, with the proportions of land and sea upon its surface as at present existing, which were important elements in the case.

The depth of the ocean in equatorial and polar regions ought surely to be taken into account, as it was quite possible to conceive of the irregularly shaped solid portion of the globe projecting in places through a spheroidal coating of water, so as to form large tracts of land, and yet on the average forming a sphere. Such a sphere, from disturbances of its equilibrium, he believed would be much more liable to changes in its axis than a spheroid; and the nearer a spheroid approached a sphere the more sensible it would become to such disturbances.

He had never intended to suggest that the hypothetical belt was to be suddenly elevated so as to produce the enormous tidal movements of which the author spoke. On the contrary, he believed that all such disturbances of equilibrium were gradual, and that the axis of rotation and that of figure were never at any great distance from each other. There was one portion of the paper which he found difficult to comprehend. He could not conceive why

* There are two papers in the Proc. Roy. Soc. on subjects allied to that of the above paper—one by Mr. G. Darwin, vol. xxv. p. 328, the other by Professor Haughton, vol. xxvi. p. 51. The objects the writers have in view are by no means the same as mine; and they discuss questions which I have not touched; but their methods are similar to those which I have used, and, I think, it may be added that their results tend to confirm those at which I had independently arrived.

so enormous a protuberance as 125 miles over a belt 20° in width should be necessary in order to displace the polar axis by 20°, when the present equatorial protuberance was only about one tenth of that height.

Moreover the probability is that the earth, instead of being a rigid solid, is to a certain extent viscous or plastic, and that such should be the case seems quite in accordance with geological facts. If the globe were a viscous body, with a solid crust of moderate thickness, elevations such as those suggested in the Address might well suffice to bring about a shifting of the crust, either by sliding on the fluid or viscous interior, or by causing it to undergo a certain amount of gradual deformation. The thinner the crust, provided it were sufficiently rigid to support the elevations once made upon it, the more readily would its geographical position be changed with regard to the poles. With regard to the thickness of the crust at the present time, he did not despair of astronomers at last conceding a less thickness than that assigned by the late Mr. Hopkins and Sir William Thomson. He was glad to find that the latter, in his Address to the Mathematical Section of the British Association at Glasgow, was willing not merely to admit, but to assert as highly probable, that the axis of maximum inertia of the earth and the axis of rotation, always very near one another, may have been in ancient times very far from their present geographical position, and may have gradually shifted through 10, 20, 30, 40 or more degrees, without at any time any perceptible sudden disturbance of either land or water.

Mr. George Darwin, also no mean mathematician, in his paper recently communicated to the Royal Society, agrees as to the probability of large geological changes affecting the position of the poles, and regards the effects of such changes as possibly cumulative.

Mr. Evans felt that the Society was much indebted to Mr. Twisden for having likewise investigated the question, in which, of course, he was personally much interested.

Prof. Hughes presumed that those who in this discussion had suggested changes in the position of the earth's axis to account for difference of climatal conditions in past times, contemplated only a change in the geographical position of the point which we now call the pole, and not a shifting back and fore of the earth's axis of rotation to explain the phenomena of Miocene and Glacial times.

The argument, he pointed out, rested entirely upon the analogy between the ancient and recent forms of life, and that it assumed that the climatal conditions required by the ancient plants and animals must have been exactly or nearly the same as those under which their nearest living analogues chiefly flourish. But, he said, we were continually multiplying examples to prove the fallacy of this reasoning. Some creatures, as *e.g.* several common species of mice, are lively through the winter; others closely allied, as the dormouse, hibernate. We are continually hearing of the discovery in Arctic regions of forms of life we should have expected only in subtropical or temperate regions, as *e.g.* many Echinoderms.

The whole circuit of the northern regions was being rapidly explored, and everywhere the temperate forms of life were found dying out towards the present Pole in ancient time as now; whereas if the Pole had shifted we ought to find evidence of what became the polar regions when the ancient plant-bearing Arctic regions had been drawn down into more temperate zones.

Prof. Ramsay referred to the former prevalence in geology of views which had long since been exploded, and expressed his opinion that before long the theory of the fixed geographical position of the poles of the earth would share the same fate. The flora of various deposits in Polar lands indicated the growth of plants which would require the stimulus of light, even if the necessary amount of heat for their growth could be accounted for. With respect to great local changes of level, he remarked that the northern part of Africa was below the level of the sea in very recent times; and there was reason to suppose that even later than the Miocene epoch a vast tract of land occupied the space between what were now the continents of Africa and Asia. Of course no one supposed that the position of the poles had been changed by rapid upheavals of land; but as we know that all geological changes of level have been slow and gradual, so the poles may have altered their position by a process as slow as that evolution which has originated the species of animals and plants during the long series of geological time. Such questions as these were serious, involving the results of much observation on the ground, and could not, he thought, be solved in the closet by any amount of abstract work alone.

Mr. A. W. Waters called attention to the large amount of matter removed from one position to distant positions; for the amount of solid matter carried down by rivers in solution is enormous, something like 5,000,000,000 tons being annually removed from the land surface, which is equal to the weight of Vesuvius removed in ten years. This gives a gain to the southern hemisphere of about 3,500,000,000 tons per annum, or one Vesuvius in fourteen years; but from Mr. Twisden's figures, the weight of Europe would have to be removed 166 times to give a change of 20 degrees. The calculations of the author are all based upon the earth being perfectly rigid; but this geologists cannot admit, considering the movements of the crust in continental and mountain elevation; and Sir William Thomson said in his Address at Glasgow, that if the earth were as solid as steel it would still take the same equatorial bulge. The geographical position of the axis might then be changed, and yet the axis always hold the same position with regard to heavenly bodies.

Rev. J. F. Blake remarked that mathematics can only give true results if they have true observations to work upon. The results in the present case came out much smaller than non-mathematicians would suppose. He questioned whether so great an amount of divergence as was sometimes assumed was possible, but at the same time the effects of change of figure would be cumulative. Elevations and depressions consequent upon something going on in the interior of the earth would cause the axis of figure to depart from the axis of rotation; and changes of form would result in order to bring them again into coincidence. In this way there seemed to be no limit to the change of position.

Prof. SEELEY pointed out that the supposed necessity for moving the earth's axis of rotation depends upon palæontological considerations, and inferences as to the conditions of existence of extinct organisms, of the ways of life of which we are necessarily ignorant. He cited the Musk Ox and other animals as still living in high northern latitudes, and inferred that if food can be found for animals so high in the scale of organization, it is reasonable to believe that any of the lower animals might exist in those regions under the present climatal conditions. It had been supposed that the absence of light in the long arctic winter was unfavourable to the existence of such plants as had been met with fossilized in arctic latitudes; but since Palms and other plants actually brought from the tropics survive the winter in St. Petersburg, matted down in absolute darkness for more than six months, it must be concluded that high types of plant-life may become acclimatized to conditions very different from those under which they at present live; and if plants in certain floras in the southern hemisphere are regarded as showing any relation with Eocene plants of Europe which indicates that the living forms are descended from the old European stock, then those Eocene plants must have passed through a great variety of climatal conditions without undergoing much modification before they reached their present localities. Hence he concluded that our knowledge is not at present sufficient to allow us to dogmatize on such great questions.

The AUTHOR said that so many questions had been asked that even if he were able to answer them time would not permit. He would only make two remarks. *First.* He had not attempted to work out the subject in all its bearings, but to examine one view of the case. The fact is that no question can be answered mathematically unless put into a definite form. The object of such an investigation is to take a definite view of a given question, and to see what comes of it. This is what he had endeavoured to do in the present case. He was, of course, aware that there is great uncertainty in the data of the question when regarded more broadly; *e.g.* the constitution of the interior of the earth is but very partially known. In the *second* place, he ventured to think that one of his results had an application to any way that might be taken of treating the question, viz. the proof that the amount of transferred matter must be at the least a considerable fractional part of the whole equatorial bulge, if a considerable change is to be effected in the geographical position of the pole, and that even this large quantity would have to be greatly increased unless it were moved from a favourable position to a favourable position; *e.g.* if matter is transferred from one position to a neighbouring position, the quantity might be very great and the effect but small.

4. *On* Terminal Curvature *in the* South-western Counties. By W. A. E. Ussher, Esq., F.G.S. (Read June 20, 1877.)

(By permission of the Director of H.M. Geological Survey.)

Introduction.

More than two years ago my attention was drawn to this subject by the perusal of a paper by Mr. Mackintosh in vol. xxiii. of the 'Quarterly Journal.' Having in the interim neglected no opportunity of studying the phenomena in question over a large area, I arrived at conclusions adverse to those advocated by Mr. Mackintosh; so that the object of this paper is twofold:—first, to controvert Mr. Mackintosh's opinions; secondly, to put forward more tenable explanations. To carry out this object thoroughly is impossible without considering the Pleistocene history of Devon, &c., in some at least of its aspects; but as the wider subject is reserved for a future communication, I shall here only touch on it as briefly as possible.

Part I.

Mr. Mackintosh suggests four explanations of the instances of terminal curvature described in his paper*. They are as follows:—

1st. "Land-ice filling up the basin of the Bristol Channel" and travelling southward.

2nd. Floating ice, in bergs or in "any other form."

3rd. "A swift oceanic current exerting a pressure on the underlying slates by means of a forcible drifting forward of detritus."

4th. "A still more violent rush of waters caused by a sudden upheaval or depression of the land."

The first of these alternative solutions finds most favour with their author. I do not deny its applicability to some instances of terminal curvature within three or four feet of the surface in glaciated districts; but in the South-western Counties, where evidence of ice-action has not been hitherto detected, this phenomenon can in no wise be cited as a proof of it, for the following reasons:—

First, such an assumption ignores the great surface-waste and contour-moulding which these counties underwent during Pleistocene times, whilst it entails the preservation of numerous parts of an old glaciated surface of which all accompanying signs have been swept away.

Secondly, beds exhibiting terminal curvature are frequently visible in situations which, during the Glacial epoch, must have been too far removed from the suppositional ice-bed to have sensibly felt the pressure of an ice-mass.

Thirdly, if the south-western counties really experienced the rigours of the Glacial epoch, when we consider the nature of beds

* Quart. Journ. Geol. Soc. vol. xxiii. pp. 326 *et seq.*

capable of mechanical flexure near the surface, and couple with it the extensive waste of Pleistocene times, the survival of glaciated surfaces composed of shales would be little short of miraculous, considering that hard grit and igneous rocks nowhere in these counties present *moutonnées* or striated surfaces.

In following the course of the Exe above Dulverton, not far from Barlynch Abbey, I noticed a face of hard grit crossed by parallel grooved lines. This, I believe, is the spot visited by the late Prof. Jukes, and rightly, I think, described by Mr. Whitley as a slickenside *. It does not resemble a *moutonnée* surface.

Fourthly, the intrusion of extraneous substances, as well as the formation of extensive moraines of local materials, would accompany the nascent flow and dwindling away of so powerful an agent as land-ice in the form advocated by Mr. Mackintosh. Yet we have no clear indications of moraine-matter in Devon.

The Boulder-gravels of the Dart † and Teign ‡ valleys might be the relics of old moraines carried down to lower levels in the further excavation of the valleys, having been re-sorted and well water-worn in the process; but the proximity of granitic or slaty rocks, of which they consist, and the concession of greater force and volume to the former representatives of the present streams would equally entitle one to refer them to fluviatile deposition alone.

Notwithstanding the paucity of possible signs of Glacial action in Devon, I am inclined to think that the absence of deposits commensurate with the great Pleistocene denudation experienced by the South-western Counties § may be due, in the first place, to some powerful denuding agent in the form of a local ice sheet or glacier system, and, in the second, to the great force and volume of surface-water likely to be liberated at the close of a period of Arctic severity.

But the instances of terminal curvature given by Mr. Mackintosh do not seem to be ascribable to land-ice in any form. The absence of terminal curvature on the northern slopes of the Brendon Hills is against the idea that the phenomena were produced by the surface-ruffling action of a hill-ignoring ice sheet or the pressure of ground-moraine between slaty laminæ; for the greatest force would be expended on the slopes affording most resistance to the southerly movement of the mass, whilst on the coincident declivities its effect would be proportionately less. To regard the northern slopes as unmoulded whilst the hilltops and southern declivities present their present forms is a way out of the difficulty that cannot well be entertained.

Mr. Mackintosh's remaining alternatives postulate great changes in the physical geography of the country. To ascribe the production of terminal curvature on the Brendon Hills to the action of

* Geol. Mag. vol. v. p. 31.
† Trans. Dev. Assoc. for 1876, p. 427.
‡ Quart. Journ. Geol. Soc. vol. xxiii. p. 418, and Geol. Mag. vol. vi. p. 40.
§ Comp. Buckland and De la Beche "On the Geology of Weymouth," Trans. Geol. Soc. 2nd ser. vol. iv., and Pengelly, Geol. Mag. vol. iii. p. 573.

icebergs or floes entails either (α) the participation of the South-western Counties in the submergence affecting Wales and the Midland Counties, and to such an extent as to allow the flotation of large bergs over the lesser elevations, and to admit of their stranding on the greater heights, then existing as shoals in an Arctic sea; or (β) the depression of these counties to a depth not sufficient to allow of the flotation and stranding of large bergs, but suitable for the accumulation of pack and floe ice. In either case the impact of bergs or floes upon tracts barely submerged would be capable of producing considerable disturbance in beds at and near the surface, but could scarcely produce uniformity in their disturbance or reversal*. In the case of bergs one would certainly expect to find some evidence in the form of Boulder-clay and scattered erratics; yet no instances of either can be adduced.

The clay deposits of Roundswell, &c., near Barnstaple, described by Mr. Maw †, and the clay with worn fragments near White Staunton, on the Blackdown, mentioned by Mr. H. B. Woodward (in a letter to the 'Geological Magazine,' quoted by Mr. Croll) cannot be regarded as Boulder-clays, as the former is of subsequent date to the raised beaches, and the latter appears to have resulted from the redistribution of Cretaceous material and old gravels (probably Tertiary) by fluviatile agents.

With the exception of the granite boulder of Saunton, described by the Rev. D. Williams ‡, which from its position does not apply to my objection, no erratics have, so far as I am aware, been detected in these counties.

These appear to me to be fatal objections to the idea that Devon was totally submerged during the Glacial epoch.

To admit Mr. Mackintosh's remaining hypotheses would entail the submersion of heights now among the most considerable in the area, which is contradicted by the foregoing objections: to deny its application in these cases and allow of it in districts of less elevation would entail a partial submergence. The raised beaches of Devon and Cornwall do not indicate a maximum depression of more than 60 feet, and on an average do not exceed 10 feet above spring-tide high water. Mr. Pengelly's Lithodomous perforations at about 235 feet above the sea at Petitor, near Babbacombe, have been cited by Mr. Mackintosh as proof of a Pleistocene depression to that amount in South Devon. "They clearly show," he says, "that the sea has been the last modifying agent to which the land has been subjected." This conclusion is at variance with Mr. Pengelly's opinion that "the Petitor borings are older than those of Kent's Cavern; yet the latter belong to a period of higher antiquity than that in which the red loam teeming with remains of extinct mammals was carried into the cave"§.

* Near Raleigh's Cross Mr. Mackintosh notices the prevalent S.S.E. direction of the reversed laminæ. His other observations tend to prove a comparative uniformity in the direction of the curvature.

† Quart. Journ. Geol. Soc. vol. xx. p. 447 *et seq.*, and Geol. Mag. vol. ii. p. 525.

‡ Trans. Geol. Soc. 2nd ser. vol. v. p. 287.

§ Trans. Dev. Assoc. for 1866.

On a hilltop half a mile W.N.W. of Goodrington, near Paignton, I observed a large weatherworn limestone boulder lying on the surface, with several perforations extending from $\frac{1}{8}$ to $1\frac{1}{2}$ inch from the surface, and making angles of from 30° to 80° with it. The sides of the cavities were generally smooth; in two of them dead shells, apparently of *Helix nemoralis* in a fragmentary condition, were discovered. The boulder occurs at more than 200 feet above the sea. It may have been brought there, though for what purpose it is hard to say.

Granting the subsidence of this part of Devon to a depth of 300 feet, the absence of any corroborative evidence elsewhere proving subsidence to a greater extent than the maximum height of the raised beaches precludes the ascription of a corresponding depression to other parts of Devon and to Somerset and Cornwall.

The amount of meteoric abrasion that must have taken place since the raised-beach formation would be more likely to cause the obliteration of perforated rock-surfaces (those observed being in exposed situations, and having, I believe, lately disappeared) than to remove all traces of a sea-wrought configuration.

How far certain species of land-shells may be capable of dissolving out cavities in limestone rocks has not, I believe, been ascertained.

These considerations are adverse to suggestions involving a partial submergence to the depth of a few hundred feet.

Even conceding the most favourable physical conditions, I am at a loss to conceive how any oceanic current, no matter how powerful, could twist back the laminæ of the most flexible shales, except as directing the course of floe, pack, or berg ice.

Mr. Mackintosh's last suggestion, of a violent rush of waters occasioned by a sudden upheaval, or depression, savours more of cataclysm than connexion in any way with the phenomena under consideration.

If the "weight of the hill" means any thing, it merely expresses conditions favourable to the production of slips, by percolating waters rendering a clayey substratum slippery, by the action of wedging frosts, or similar agencies. If it were a natural force, capable of producing reversal in shales outcropping on slopes, terminal curves would be confined to hillsides and would be of much more frequent occurrence than they are.

Transportation of Blocks.

Under this head Mr. Mackintosh notices on Brendon Hill "a considerable thickness of reddish loam" overlying slaty débris and intermixed with fragments of slate and quartz blocks of large size, the latter being "at considerable distances from their native veins." He ascribes the transport of these blocks to the agent which caused the displacement of the slaty laminæ, or to "a subsequently operating cause." This is evidently an instance of Head, a name applied to the accumulation of loam with angular stones so frequently exposed in the Palæozoic cliffs of Devon and Cornwall, attaining in some places, as by the shores of Barnstaple Bay, 100 feet in thickness. Whether the Head is regarded as a mere talus from the weathering of adjacent exposed rock-surfaces, or as accumulated under very different climatal conditions from those now prevailing, the following observations are equally applicable:—

First, the accumulation is not now forming to any appreciable extent, judging from those exposed portions of the Palæozoic area where the accumulation of talus is now taking place. The Head on the coasts is evidently the débris of a more ancient period.

Secondly, the coast Head was accumulated after the formation of the raised beaches, being always uppermost when both are exposed in the same cliff. Having observed more than thirty instances of raised beach on the Cornish coast, I can verify Mr. Carne's conclusion on this point.

Thirdly, the coast Head was formed long prior to the submergence of the forests and the formation of the present Secondary cliff-line. The occurrence of Head on cliffs flanked by bare rock landwards where no modern talus could rest, and the isolation of rocky pedestals bearing pinnacles of Head, as on Godrevy beach, Cornwall, and near Start Point, South Devon, sufficiently prove this conclusion.

Fourthly, during the accumulation of the coast Head the land stood at a higher level; for the submarine forests prove that elevations of at least 30 feet must have taken place prior to their growth. The nature of the accumulation indicates a period of great subaërial waste; its position evidences a more extended coast line; both combined evidence the coexistence of a more marked or rigorous climate and a greater elevation of land.

Part II.

All instances of terminal curvature in Devon, Cornwall, and Somerset I ascribe to one or other of the following three distinct causes:—

The first and far the oldest of these are the great and oft-repeated internal movements to which the Palæozoic rocks were subjected. The curves, flexures, and contortions produced by them being planed down by denuding agents, exhibit all varieties of surface-structure, one of which, resembling reversal in dip (probably in most cases resulting from the denudation of an anticlinal curve), is named "Terminal." Curves of this class are frequently met with in the vicinity of faults.

Examples.—The Gupworthy tunnel-section, revealing "the uniform curving-back of laminæ on a very gigantic scale, the vertical extent of curvature amounting to at least 20 feet"*. The quarry-section near Slapton (fig. 1, p. 54), and the instances mentioned by Mr. Mackintosh in the neighbourhood of Wiveliscombe, furnish examples of this kind of curvature not in the immediate vicinity of faults.

The Barnstaple and Taunton Railway-cutting at Horridge Down, near Wiveliscombe (shortly before this part of the line was opened),

* Quart. Journ. Geol. Soc. vol. xxiii. p. 325.

Fig. 1.—*Quarry in an Orchard to the south of Slapton.*

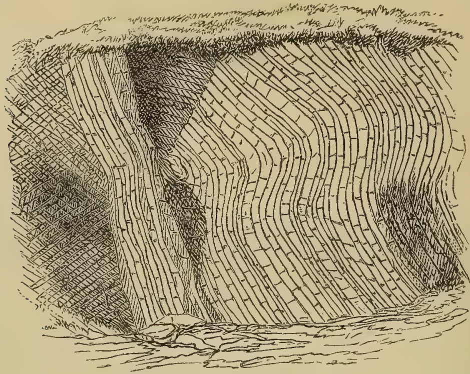


Fig. 2.—*Culm-Measure Grits and Shales exposed by the highroad between Torrington and Bideford, opposite Wear Gifford.* (Section from 4 to 6 feet in height.)

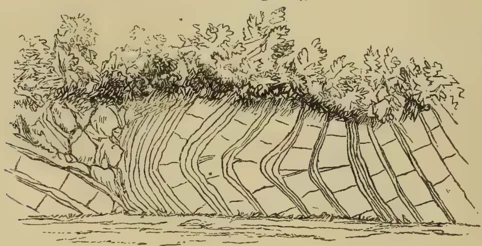
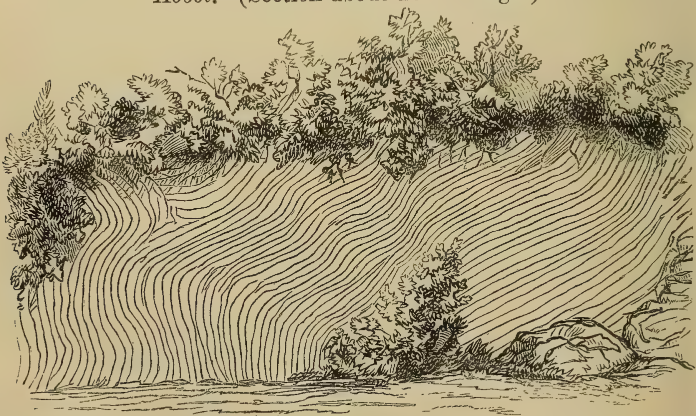


Fig. 3.—*Devonian Slate between Houghton and High Week, Newton Abbot.* (Section about 10 feet high.)



Curves due to contortion by faulting and upheaval. Small surface-curves due to intrusion of roots from above. On the right hand a boss of greenstone.

disclosed a section consisting of bluish-grey (? Devonian) shales faulted against Triassic sands. At the fault the shales are curved into an S-shaped form. If this section merely revealed the uppermost curve of the shales, any one on the look-out for terminal curvature as a proof of ice-action would accept it as an additional sign.

Fig. 2 shows a sketch section of a road-cutting between Great Torrington and Bideford, in which numerous faults are exposed; terminal curvature, probably due to the intrusion of fault rock, is exhibited.

The Culm-measures of North Devon, near Torrington, Eggesford, Merton, &c., are often flexed at such acute angles that the detection of faults by dip, unless shown in section, is impossible. By the road from Exeter to Cowley Bridge the Culm-measures exhibit an extraordinary amount of flexure. Near Holcombe Burnell * flexures from proximity of faults, fan-shaped structure, &c. are visible. These are a few of many instances which I might cite as examples.

The second cause assigned is the intrusion of wedging frosts between the laminæ of shales, leaving earthy matter filling up the gaps produced by them, on the approach of summer. This has been advocated by Mr. Godwin-Austen † in explanation of a section of contorted shales at Gurrington, near Ashburton. I have seen counterparts of the section he gives in illustration in many parts of the Culm-measure area. In times past, judging from evidence of a more rigorous climate furnished by the Head, searching frosts may in many cases have produced superficial curves and contortions in soft shales.

The third and most common cause of strictly superficial curvature is the intrusion of roots acting as wedges. The hedge banks of Devon afford many examples of this action in the Palæozoic area; and the continuity of the layers in the Triassic pebble-bed is often broken from a similar cause.

Near Newton Abbot a road-section, of which I give a sketch (fig. 3), was pointed out to me by Mr. H. B. Woodward. The surface-curvature is partly due in this case to the intrusion of roots; but the general contortion is apparently due to a more deep-seated cause.

In conclusion I would suggest the possibility of surface-curvature having been produced in spots where no roots can now be found, by the intrusion of the latter, though subsequent decay has left no other trace of their former existence.

* In Ordnance Sheet 22., S.E. of Exeter.

† Trans. Geol. Soc. 2nd ser. vol. vi. part 2, p 437.

5. *On the* Cretaceous Dentaliidæ. By J. S. Gardner, Esq., F.G.S.

(Read June 20, 1877.)

[Plate III.]

In this paper are described and grouped the shells of the family Dentaliidæ which have been obtained from the Cretaceous rocks of Great Britain. It includes all the forms I know of; but there may be in local museums and private collections specimens I have not seen.

In the genus *Dentalium* I have included all the forms belonging to this family which are not fissured at the apex, and those which are not swollen or constricted at the aperture.

The Cretaceous species here described, included in the genus *Dentalium* thus constituted, may for the present be arranged under two subdivisions.

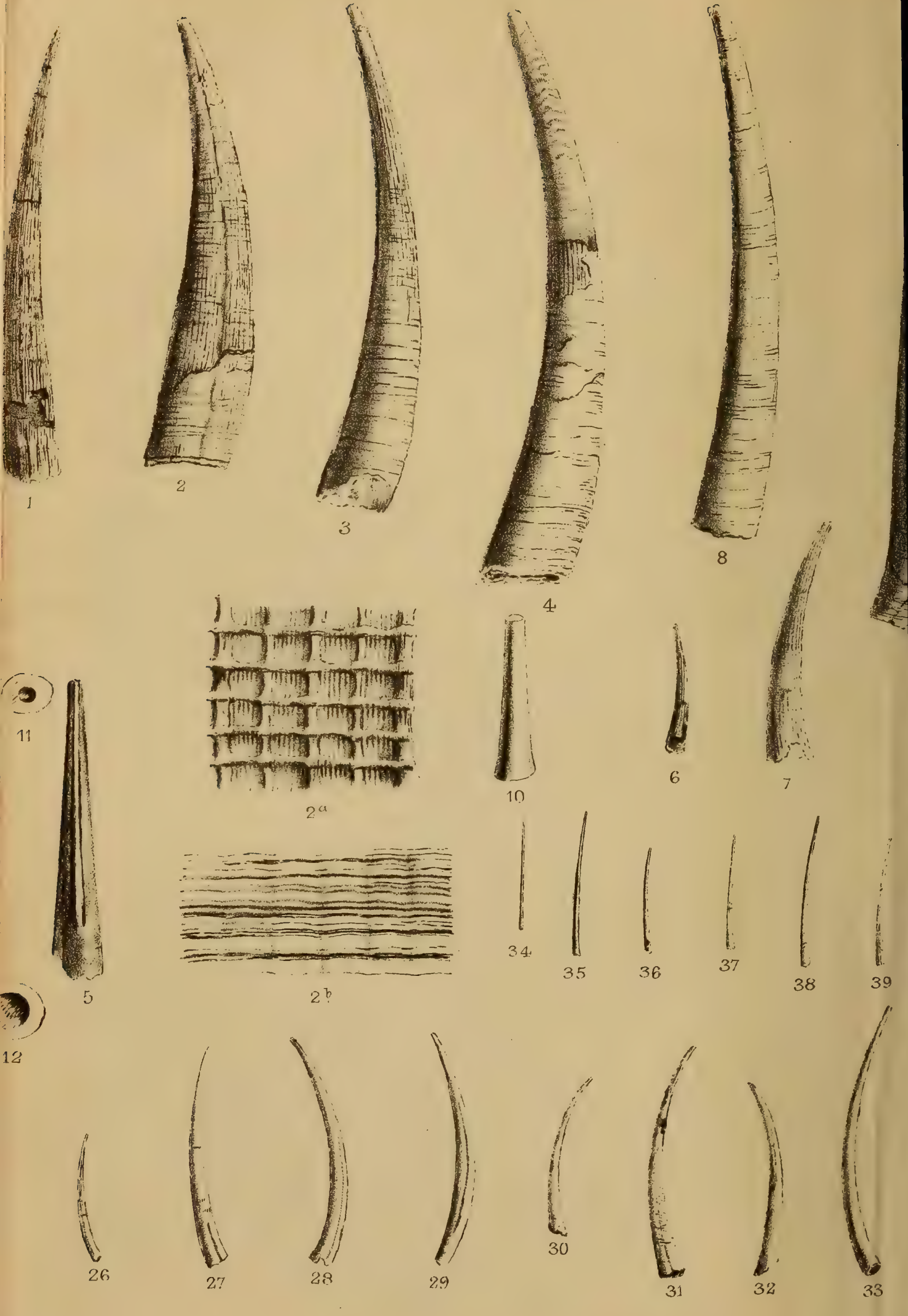
A. *Dentalium* proper, comprising the larger forms, all of which are striated.

B. The smaller and smooth forms.

In the first of these groups four species are described: two of these are new; and two, *D. decussatum* and *D. medium*, which were given by Sowerby in the 'Mineral Conchology,' are redescribed, as it seemed to me that his descriptions are incomplete. My description of *D. decussatum* is based on more than 50 specimens in my collection; and with it I have been able to incorporate *D. striatum* and *D. ellipticum* of Sowerby, as they are not distinct species. The latter was regarded by D'Orbigny as a synonym of *D. decussatum*. The description of *D. medium* is based upon specimens in the British Museum, the Jermyn-Street Museum, and Mr. Meyer's collection. Sowerby's figured specimen is evidently an internal cast, in which, of course, no trace of external markings was preserved; but a perfect specimen is figured, Trans. Geol. Soc. vol. iv. pl. xviii. p. 343. Much confusion has arisen, owing to the imperfection of Sowerby's original figure and to an unfortunate mistake in putting together in his collection both smooth and striated *Dentalia* from Blackdown. Of the two new species, I have named a very long and slender shell, like some of the recent *Dentalia* in aspect, *D. divisiense*; *D. alatum*, the other form, demands special notice, as it possesses two lateral ledge-like expansions, the use of which can only be guessed. There are species, however, among the Cretaceous *Dentalia*, much thickened laterally, which seem to lead up to this form, in which the thickening culminates. *D. decussatum* seems to show us that some of these Gault *Dentalia* had the power of thickening their shells generally to an almost indefinite extent. The rugose and uneven appearance presented by some seems to indicate that individuals among them lived to a great age. Besides these species, Dr. Fleming long since described one under the name of *D. septangulare* *, which I have never seen; and since the reading of the present paper I have described a new species from the Grey Chalk of Dover under the name of *D. majus* †.

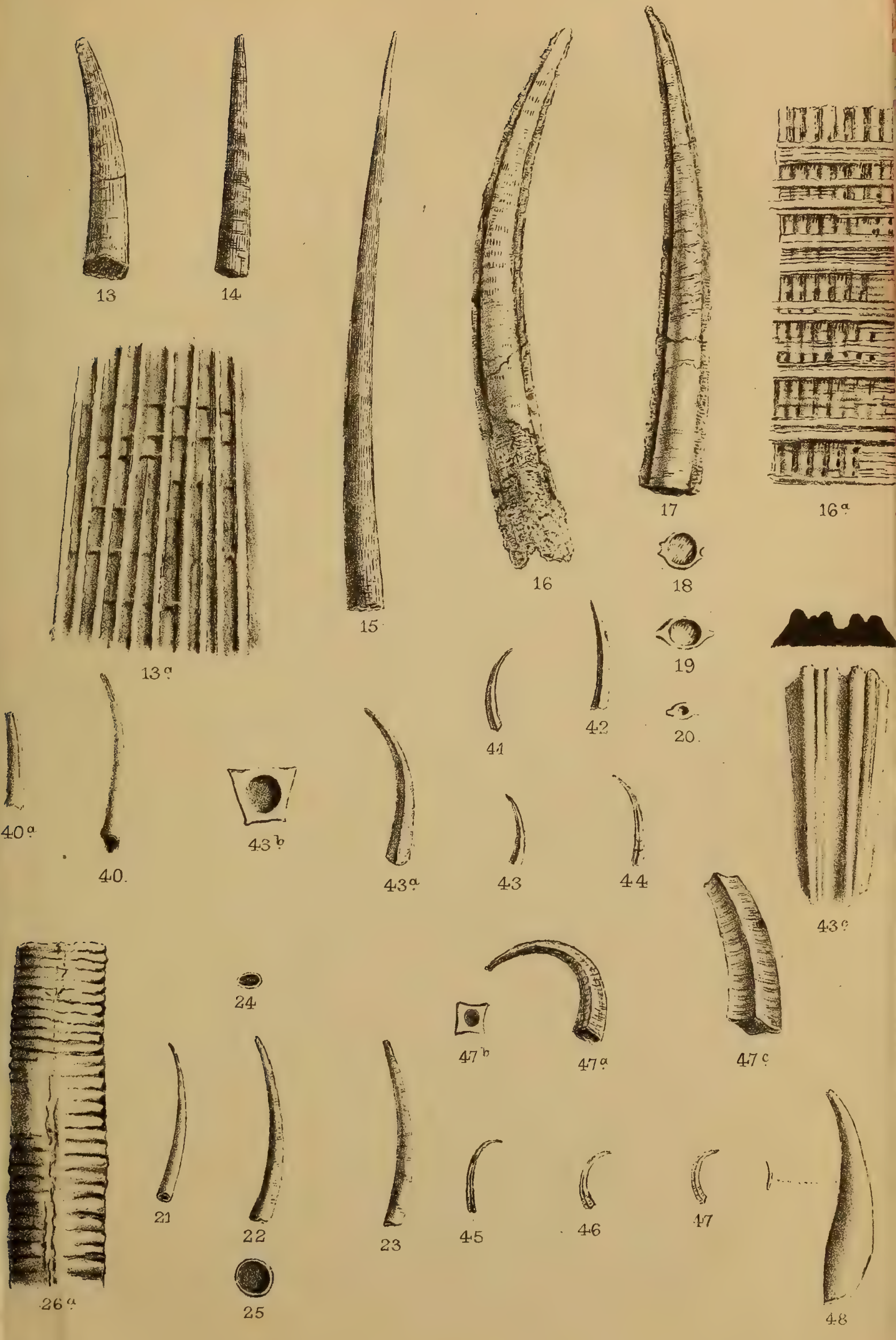
* Edinb. Phil. Journ. xii. pl. 9.

† Geol. Mag. n. s. vol. iv. p. 556.



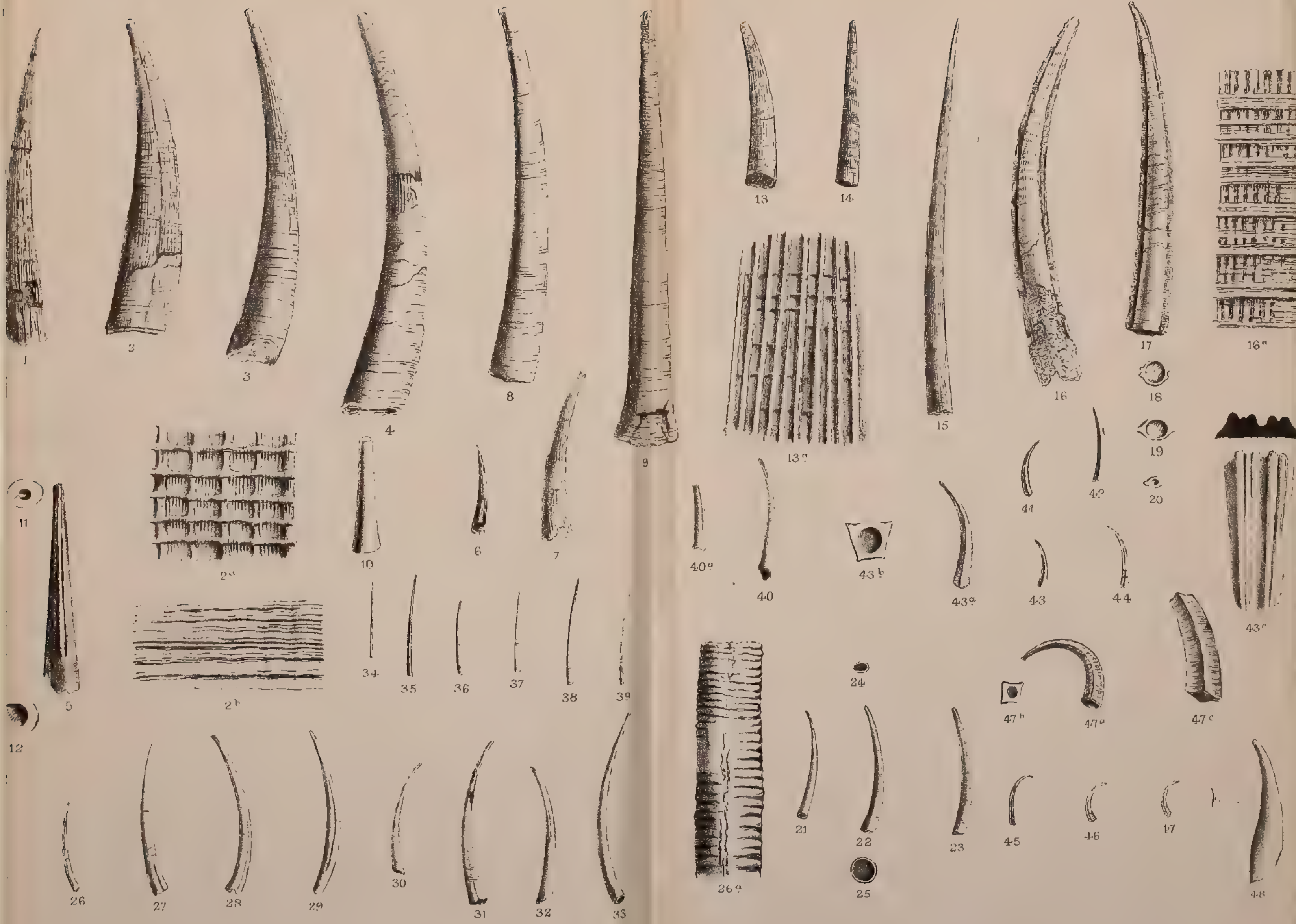
G. De Wilde lith

BRITISH CRETAC



Mintern Bros. imp.

S DENTALIIDÆ.



G. De Wilde lith — Mintern Bros imp.

BRITISH CRETACEOUS DENTALIIDÆ.

The second group, B, comprises only smaller and comparatively smooth forms. In this group three species are described: two are new; and one is redescribed, viz. *D. cylindricum*, Sowerby. There is no doubt that many others exist and may be added at a future time. *D. cylindricum* is only known in England from Blackdown; and its history is curious. Under this name Sowerby described, in the 'Mineral Conchology,' vol. i. tab. 79. f. 2, p. 179, a group of *Ditrupa plana* in ochreous earth from the Eocene at Emsworth. By an accident Emsworth was printed Exmouth; and the fossils have therefore ever since been supposed to be of Cretaceous age. In Sowerby's tables of fossils in Fitton, 'Geological Transactions,' 2nd ser. vol. iv. pp. 240 and 364, the error is repeated. Instead of rejecting the name as a synonym of *Ditrupa plana*, it is applied to the smooth Blackdown form, to which in collections this name is generally seen attached. A second species, more or less regularly ringed, is abundant in the Gault, and has been named *D. Jeffreysi* in compliment to Dr. Gwyn Jeffreys, to whom I am under obligations for assistance in the preparation of these descriptions. The third species is new and very distinct, possessing the small, needle-like aspect described by Deshayes as characterizing *D. acicula* of the Eocene; it is named *D. acuminatum*. Besides these Mr. Baily has described a fourth species, *D. cœlatulum*, from the Upper Greensand of Aberdeenshire *; but this I have not seen.

The next genus, *Entalis*, is represented by a unique specimen which was detected by that excellent observer Mr. Meyer among the common *Dentalium cylindricum* of the Blackdown beds. It is not unlikely that other specimens exist, unknown to the owners, in the numerous collections from this locality; and I would therefore call their especial attention to the fact that, although of the same size as *D. cylindricum*, it is perfectly smooth and of an even texture, whilst the former is rugged and ringed by lines of growth, the fissure being besides very distinct, long, narrow, and reaching $\frac{1}{8}$ the entire length of the shell. Even where, as generally happens, the slender end of *Dentalium* is broken off or not sufficiently cleaned from the matrix, the smooth texture should call attention to it. None of the Gault forms are fissured, as I have convinced myself by an examination of over 300 specimens.

The genus *Siphodentalium*, to which at present only two species are here referred, will probably soon be enlarged. It is but quite recently I have found specimens in the Cretaceous clays; and further investigation will no doubt add to our knowledge. Both the species resemble *S. quinquangulare* of Forbes, and more nearly *S. tetragonum* of Brocchi.

The genus *Cadulus* is represented by a minute species of about the size of *Cadulus subfusiformis*, Gwyn Jeffreys, which is remarkable as being the first described from rocks so old as the Cretaceous in Europe. A species has been described from rocks supposed to be Cretaceous, in California. The method of growth of this shell is not very apparent. So far as I am aware, the young shells of

* Quart. Journ. Geol. Soc. vol. xiii. p. 87, pl. ii. fig. 8.

Cadulus are nearly of the same proportions as those of the full-grown animal, but differ in being transparent, whilst what I suppose to be the older shells are opaque and glossy. If they increased in layers, in the manner common to most Mollusca, half-grown individuals would be funnel-shaped, $\frac{2}{3}$-grown would show the broad end closing in, which closing would continue until the full-grown shape was reached. None of these intermediate forms have ever been found; and the question naturally presents itself whether the shell does not begin to be formed over the fully grown animal, first as a membrane, and gradually thickening until it becomes opaque. This idea receives some confirmation from the fact that no shell of any species of *Cadulus* shows traces of rings, but all are, on the contrary, smooth.

The examination of this family, the Dentaliidæ, in its range through Cretaceous rocks, shows that the forms which these tubular shells have assumed have been no less persistent than those of the patelliform shells. The smooth forms of *Dentalium*, the *Entalis*, *Siphodentalium*, and *Cadulus* have remained almost unchanged from far back in the Cretaceous period, through the Eocene, and have persisted until now. The striated forms with thickened shells also still exist in many recent species; but the large alate striated forms seem to have developed and become extinct in but a portion of Cretaceous time.

Genus Dentalium.

Group A.

Dentalium decussatum, J. Sby. *Gault.* (Plate III. figs. 1–12.)

Shell cylindrical, thick, moderately curved, gradually tapering; apex obtuse, entire; internally smooth and polished, without groove; internal cast gradually tapering, with the impress of the muscular attachment. *Sculpture*: 12 unequal, rounded, longitudinal ribs extend from the apex to about $\frac{2}{3}$ the length of the shell in full-grown specimens; at about $\frac{1}{5}$ of an inch from the apex other ribs are inserted, and again others rise, until, near the point of disappearance, 50 may be counted; the ribs which continue from near the apex are the more strongly marked throughout; upon an average every third rib is more prominent until near the point of disappearance, where they become equal: the ribs are frequently marked by lines showing interruptions of growth and by slight swellings: they are crossed by strong, irregularly spaced, rounded striæ, sometimes close together, sometimes with an interval of 3 times their own width; these striæ become most closely set towards the aperture; slight swellings are visible at the intersection; the whole shell is covered with fine longitudinal striæ. L. 3·25 in. B. 0·4125 in.

Sowerby described this form in the ‘Mineral Conchology,’ vol. i. p. 101, tab. 70. f. 5, from a very distinctly striated fragment. In Mantell’s ‘Geology of Sussex,’ he has named a smaller specimen *D. striatum* (fig. iv. pl. 1). It is *D. bicostale* of De Ryckholt, who also provides a name, *D. Geinitzianum*, for the specimen of the same shell figured in Mantell. *D. rhodani*, *D. cidaris*, *D. alternans*, *D. Nysti* are also closely allied, if not identical forms.

D'Orbigny gives an excellent figure of the species in the 'Paléontologie Française;' but Alth's figure in Haidinger's Abhandlungen is more slender, has stronger ribs, and is perhaps distinct.

This species is everywhere abundant in the Gault. Casts are common at Cambridge.

D'Orbigny, in the 'Paléontologié Francaise,' unites *D. decussatum* and *D. ellipticum*; and I have now satisfied myself that *D. ellipticum* is really an old and thickened form of *D. decussatum*. It is slightly elliptical externally, but retains the cylindrical inner tube, very thick near the apex, margin thin. The sculpture has nearly entirely disappeared, there being more or less obscure traces of ribs only; and the shell is marked by uneven lines of growth, giving it a weathered and generally coarse and clumsy appearance. The cast, owing to the thickness of the shell, is slightly funnel-shaped or bell-mouthed.

This form is described and figured by Sowerby in the 'Mineral Conchology,' vol. i. p. 161, tab. 70. f. 6, 7. He had seen but short pieces of the thicker end of the shell, and named it from the elliptical aperture. A similar fragment is figured in Mantell's 'Geology of the South Downs;' and the name also occurs in Fitton's list of Blackdown fossils in the Strata below the Chalk (Trans. Geol. Soc. 2nd ser. vol. iv. p. 362). It has been very generally assumed, and Stoliczka states, in the 'Palæontologia Indica,' that "*D. ellipticum* is known to be a cast of *D. decussatum*;" but the shell was not described from a cast. It has no distinctive specific characters; and the occasional remnants of ribbing generally visible prove it to be a very old form of *D. decussatum* much thickened, with the ribs obliterated by age.

It is common in the Gault, usually in the lower part; and casts are abundant at Cambridge.

Dentalium medium, Sby. *Blackdown Beds.* (Plate III. figs. 13, 14.)

Shell cylindrical, slightly curved, slender, thin: apex small, entire: *sculpture,* more or less regular longitudinal ribs, of which 18 or more of the most prominent are persistent from the apex, the rest increasing, as in *D. decussatum*, to about 40, most pronounced on the convex surface; on some specimens these ribs are tolerably regular, on others very irregularly spaced, crossed by indistinct lines of growth and varices. None of the specimens met with appear to be perfect, and therefore the dimensions are unknown; the longest specimen in any collection I have seen is about 1·1875 in. B. ·2083 to ·25 in.

This species is ribbed in the same manner as *D. decussatum*; but, owing to its mineralized condition perhaps, the ornament is far less sharp. There are no transverse striæ, but only lines of growth. The aperture, in the specimens known to me, is invariably imperfect, probably through carelessness in extracting them from the matrix. Should any of these be nearly perfect and full-grown, which does not appear to me to be the case, they would be distinguished from *D. decussatum* by being ribbed all over.

D. medium was figured in the 'Mineral Conchology' (vol. i. p. 181, tab. 79. f. 5) from a small fragment of an internal cast without markings of any sort; and what is visible of it presents no direct evidence as to whether it was striated or not. Mounted on the same tablet with the figured specimens are others found subsequently, both smooth and striated. Sowerby was evidently unaware, at the time he wrote his first description of the species, that there were more species than one in the Blackdown beds; the size of the original specimen, however, indicates it to be the striated species, the smooth being smaller and more slender. Setting the original figure aside, there are excellent engravings of the striated species, by J. de C. Sowerby, in the Trans. Geol. Soc. 2nd ser. vol. iv. pl. 18, p. 343. De Ryckholt, who had never seen the actual specimens, states that *D. medium* has no longitudinal striæ, but is covered with prominent folds of growth. Geinitz, Reuss, and Pictet have fallen into the same error. The synonymy of foreign writers cannot be unravelled without comparison of the actual specimens.

This shell appears to be very abundant at Blackdown. Dr. Gwyn Jeffreys has kindly shown me specimens of *D. capillosum*, a deep-sea form, which bears some resemblance to this species.

Dentalium divisiense, sp. nov. *Upper Greensand.* (Plate III. fig. 15.)

Shell very gradually tapering, extremely slender and elongate, slightly curved: *sculpture*, from 20 to 25 even, slightly flexuous ribs extending from the apex to the aperture without any apparent increase in their number. L. 3·125 in. B. ·2 in.

The specimen, which is distinguished by its long and slender aspect, is from Devizes. It is now in the Jermyn-Street Museum, and remains unique.

Dentalium alatum, sp. nov. *Gault.* (Plate III. figs. 16–20.)

Shell moderately curved, elliptical externally, cylindrical internally; thin at aperture, becoming very thick at apex; laterally keeled; ribbed longitudinally and decussated; growth irregular and uneven. L. 2·75 in. Width of cylinder only at aperture ·25 in.

The cylindrical tube of this shell is bordered in its entire length with two lateral flanges or flattened ledge-like expansions, each about half the diameter of the cylinder and least prominent near the aperture. These flanges readily become detached and leave a groove-like scar (fig. 18). The surface of the shell is ribbed, and decussated by fine transverse striæ, which are more closely set and less prominent near the aperture. The ribs are a little finer and closer together than in *D. decussatum*, the ribs of which they resemble in arrangement; they usually die away near the aperture, leaving about a fourth part of the shell nearly smooth.

The species is not uncommon in the Gault at Folkestone, but has been hitherto overlooked by collectors.

The lateral thickening, present in the species just described and in many described on the Continent, is most developed in *D. alatum*. The only existing species which is at all keeled is a much smaller deep-sea form, described by Dr. Gwyn Jeffreys as *D. ensiculus*; but this differs most essentially from ours, being neither cylindrical internally nor ribbed.

Since writing the above I have found a slightly alate form nearly 5 inches in length to be not uncommon in the Grey Chalk of Dover. This I have named *D. majus*.

Group B.

Dentalium cylindricum, Sby. *Blackdown Beds.* (Plate III. figs. 21–25.)

Shell cylindrical or elliptical, slender, elongated, moderately curved, thickened laterally, rugose with irregular varices and lines of growth, occasionally exhibiting an imbricated structure; aperture circular, margin thin; apex minute, entire. L. ·9583 in. B. ·0111 in.

This species has a clumsier appearance than *D. glabrum*, being thicker and more rugose, and appears to be specifically distinct, even after making allowance for the difference of matrix, the condition of mineralization, and the fact that the apex is seldom preserved. The uneven growth may be partly due to its sandy habitat when living; but the appearance cannot be ascribed to the condition of mineralization of the specimens, as *Entalis Meyeri*, from the same beds, is smooth.

It is difficult to realize that Sowerby was unacquainted with this form, as it is so abundant at Blackdown; but it does not appear in the 'Mineral Conchology,' the name being in that work applied to *Ditrupa plana* from Emsworth, by a mistake printed Exmouth. The mistake has been repeated in Sowerby's later works; and *D. cylindricum* does not appear in his lists of fossils from Blackdown in the Geol. Trans. 2nd ser. vol. iv., but only as being from Exmouth. I have here transferred the name to the Blackdown fossils, as it has been for a long time almost universally applied to them.

Dentalium Jeffreysi, sp. nov. *Gault.* (Plate III. figs. 26–33.)

Shell cylindrical or very slightly elliptical, slender and elongated, moderately curved, thin, smooth and polished; surface marked in places by lines of growth, transversely ringed throughout or towards the apex only. Length of the largest specimen 1·50 in., breadth ·125.

The Gault shells are usually crushed and pressed into one or more folds, giving them an irregularly grooved appearance, the grooves not usually extending the whole length of the shell. Owing to this crushing few specimens show the form of the tube; but it is cylindrical or very slightly flattened. The closely set rings cannot be observed without the aid of a lens, but are then seen to be rounded and extremely regular, sometimes present throughout the whole length of the shell. Dr. Gwyn Jeffreys has shown me similarly ornamented and undescribed specimens from the Bay of Biscay.

This species differs from *D. cylindricum*, Sby., in its smoother, thinner, and more polished and slender aspect, and from *D. glabrum*, Geinitz, by its annulation*.

It is abundant in the Gault at Folkestone; and casts, apparently of this species, are met with at Cambridge. It is also common in the cracker rocks at Atherfield, and probably in other Lower-Greensand rocks.

I have named it in compliment to Dr. Gwyn Jeffreys, whose researches in the Dentaliidæ are universally known, as a slight recognition of much valuable advice and assistance.

Dentalium acuminatum, sp. nov. *Gault.* (Plate III. figs. 34–39.)

Shell very slender and needle-like, cylindrical, thick, nearly straight or very slightly curved; surface smooth and polished; sometimes with faint lines of growth; aperture slightly elliptical; apex minute, entire. L. ·75 in. B. ·0416 in.

This is distinguished from *D. cylindricum* by its more slender and needle-like aspect, smaller size, and lesser curve. It is one of the smallest and most slender shells of the genus, resembling an Eocene form, *D. acicula*, Desh., and the recent *D. gracile* of Jeffreys. It has hitherto been overlooked, having probably been supposed to be a young form of some other *Dentalium*.

Genus Entalis.

Entalis Meyeri, sp. nov. *Blackdown beds.* (Plate III. fig. 40.)

Shell elliptical, slender, elongated, moderately curved, smooth but not polished, without any lines of growth, as thick in the middle as near the aperture; apex slender, fissured, the fissure being narrow and extending $\frac{1}{8}$ the length of the shell; aperture apparently thin and elliptical, but damaged in the only specimen known. L. ·9583 in. B. ·1041 in.

This shell is peculiarly interesting as being the first *Dentalium* having a slit described from rocks older than the Eocene in Europe. Stoliczka describes a somewhat similar but shorter form, from the Cretaceous rocks of Pondicherry, under the generic name of *Fustiaria*, 'Palæontologia Indica,' 1868, vol. ii. p. 445.

Genus Siphodentalium.

Siphodentalium affine, sp. nov. *Gault.* (Plate III. figs. 41–44.)

Shell minute, curved, cylindrical interiorly, subquadrate exteriorly. The concave or dorsal side broad, flattened, smooth,

* In Geinitz's 'Charakteristik der Schichten und Petrefacten des sächsisch-böhmischen Kreidegebirges,' p. 74, the description of *D. glabrum* is:—"Long, small, slightly bent or straight, quite smooth, with oval section." The fig. 28. pl. xviii. is much coarser than a subsequent figure in the Kieslingswalda (Pl. i. fig. 27), which is slender and has a round section.

bordered by 2 sharp and clear angular keels; the ventral surface slightly convex, with a depression in the centre, and with a rounded rib at each angle bordered on the inside by 2 other longitudinal ribs. These 2 lateral ribs and a central furrow alone are present at the apex, which is minute and cylindrical. The angularity and the ornament diminish towards the aperture, especially on the convex surface. The aperture is cylindrical and very slightly constricted, with thin margin. L. ·4307 in. B. ·0625 in.

When crushed this shell appears deeply grooved. It is more regular, smoother, and less curved than the species next described, from which it also differs in texture. I have not observed any grooves or notches in the apex; but the angulated form and constricted aperture leave no room to doubt that it is correctly placed in *Siphodentalium*.

It is very closely allied to *S. quinquangulare* of Forbes and *S. tetragonum*, Brocchi, both of which, however, present specific differences.

It is abundant in the Gault at Folkestone.

Siphodentalium curvum, sp. nov. *Gault*. (Plate III. figs. 45–47.)

Shell minute, much curved, cylindrical interiorly, quadrangular exteriorly, the angles forming sharp prominent ridges, which commence from the apex and continue to the aperture; between them are concave regions strongly marked by rings of growth; aperture round and slightly constricted, margin thin; apex small. The amount of curve, usually great, is variable, and the shell often irregular. Greatest length ·625 in. B. ·0625 in. These dimensions, it should be observed, are seldom attained.

This shell may easily be confounded with some of the young of the polygonal *Serpulæ*, which are also met with in the Gault. Still there appears little doubt that it is a true *Siphodentalium*.

It is not uncommon in the Gault at Folkestone; and Mr. Meyer possesses a specimen somewhat broader, but apparently of the same species, from the top of the Atherfield beds at Sevenoaks.

Genus Cadulus.

Cadulus gaultinus, sp. nov. *Gault*. (Plate III. fig. 48.)

Shell minute, thin, elongated, cylindrical, contracted at each end, swollen; curve of the convex side moderate, that of the ventral side more slight on account of the considerable swelling throughout the greater part of its length; polished and shining, without striæ; aperture slightly oblique, minute, constricted; apex very small and slender. Length ·20 in., breadth, at widest part, ·04 in.

This shell very much resembles *Cadulus* (*Gadus*) *brevis*, Desh., from the Paris basin, and other allied species from the Tertiaries of Europe, and the living *C. subfusiformis*, Jeff. It is interesting as being the oldest known form of *Cadulus*, no species having hitherto been recorded from Cretaceous rocks, except *Cadulus* (*Gadus*) *pusillus*, Gabb, from the Cretaceous rocks of California.

It abounds in the *Nucula-bivirgata* zone at Folkestone.

	Lower Green-sand.	Gault.	Upper Green-sand.	Chalk.
DENTALIIDÆ.				
DENTALIUM.				
A. *Longitudinally ribbed species.*				
D. decussatum, *Sby.*, partially ribbed.	...	*		
D. medium, *Sby.*, wholly ribbed	...	...	*	
D. divisiense, sp. nov., ribbed, very slender	...	...	I	
D. alatum, sp. nov., laterally keeled...	...	*		
[D. septangulare, *Fleming*, with only 7 ribs]................................	...	...	...	I
D. majus, *Gardn.*	...	...	...	*
B. *Without ribs.*				
D. cylindricum, *Sby.*, rough and irregular	...	...	*	
D. Jeffreysi, sp. nov., annulated	...	*		
D. acuminatum, sp. nov., acicular ...	...	*		
[D. cælatulum, *Baily*, finely reticulated]................................	...	...	I	
ENTALIS.				
E. Meyeri, sp. nov.........................	...	...	I	
SIPHODENTALIUM.				
S. affine, sp. nov.	...	*		
S. curvum, sp. nov.........................	I	*		
CADULUS.				
C. gaultinus, sp. nov.......................	...	*		

* abundant. I, unique or very rare.

EXPLANATION OF PLATE III.

* From the British Museum. † From Jermyn-Street Museum. ‡ From Mr. Meyer's Collection. ** From the Woodwardian Museum. The remaining specimens are in my cabinet.

Figs. 1, 2. *Dentalium decussatum*, natural size. Folkestone.
Fig. 2 *a*. „ „ ornament, enlarged, from near apex. Folkestone.
Fig. 2 *b*. „ „ ornament, enlarged, from nearer aperture. Folkestone.
Figs. 3, 4. „ „ natural size. Folkestone.
Fig. 5. „ „ cast, natural size. Folkestone.
Fig. 6. * „ „ (*D. striatum*, Sby.), nat. size. Sussex.
Fig. 7. „ „ nat. size. Folkestone.
Figs. 8, 9. „ „ (*D. ellipticum*, Sby.), nat. size. Folkestone.
Fig. 10. „ „ cast, nat. size. Folkestone.
Fig. 11. „ „ transverse section, near apex, nat. size. Folkestone.
Fig. 12. „ „ transverse section, near aperture, nat. size. Folkestone.

Fig. 13. ‡ *Dentalium medium*, nat. size. Blackdown.
Fig. 13 *a*. „ „ ornament, enlarged. Blackdown.
Fig. 14. † „ „ nat. size. Blackdown.
Fig. 15. † „ *divisiense*, nat. size. Devizes.
Fig. 16. „ *alatum*, nat. size. Folkestone.
Fig. 16 *a*. „ „ ornament, enlarged. Folkestone.
Fig. 17. „ „ nat. size. Folkestone.
Fig. 18. „ „ section near the aperture. Folkestone,
Fig. 19. „ „ section near the centre. Folkestone.
Fig. 20. „ „ section near the apex. Folkestone.
Fig. 21. † „ *cylindricum*, nat. size. Blackdown.
Figs. 22, 23. ‡ „ „ nat. size. Blackdown.
Fig. 24. ‡ „ „ section at apex, slightly enlarged. Blackdown.
Fig. 25. ‡ „ „ section at aperture, slightly enlarged. Blackdown.
Figs. 26–29. „ *Jeffreysi*, nat. size. Folkestone.
Fig. 26 *a*. „ „ ornament, enlarged. Folkestone.
Fig. 30. ** „ „ nat. size. Atherfield.
Figs. 31–33. * „ „ nat. size. Folkestone.
Figs. 34–39. „ *acuminatum*, nat. size. Folkestone.
Fig. 40. ‡ *Entalis Meyeri*, nat. size. Blackdown.
Fig. 40 *a*. „ „ apex, enlarged to show slit. Blackdown.
Figs. 41–44. *Siphodentalium affine*, nat. size. Folkestone.
Fig. 43 *a*. „ „ twice nat. size. Folkestone.
Fig. 43 *b*. „ „ section, enlarged. Folkestone.
Fig. 43 *c*. „ „ convex surface, magnified. Folkestone.
Figs. 45–47. „ *curvum*, nat. size. Folkestone.
Fig. 47 *a*. „ „ enlarged. Folkestone.
Fig. 47 *b*. „ „ section, enlarged. Folkestone.
Fig. 47 *c*. „ „ portion, enlarged to show transverse striæ. Folkestone.
Fig 48. *Cadulus gaultinus*, nat. size and enlarged. Folkestone.

6. *Notes on* Fossil Plants *discovered in* Grinnell Land *by* Captain H. W. Feilden, *Naturalist of the English North-Polar Expedition.* By Professor Oswald Heer, F.M.G.S. (Read November 7, 1877.)

In the vicinity of Discovery Harbour, where H.M.S. 'Discovery' wintered during 1875–76, a thick bed of lignite was found. The locality referred to is on the western shore of Robeson Channel, in about latitude 81° 45′ N., and longitude 64° 45′ W., north-west of Cape Murchison; the exact position is designated Watercourse Ravine in the Charts of the English Expedition.

This coal-bed has a thickness of from 25 to 30 feet, and lies in a depression, the foundation of which consists of the unconformably stratified azoic schists which constitute the chief mass of Grinnell Land. On the coal-bed rest immediately black shales and sandstones. The black, fine-grained shales, which very closely resemble the *Taxodium*-shale of Cape Staratschin on the Ice-fiord of Spitzbergen, contain many remains of plants, which were collected by Captain Feilden and handed over to me for examination. The coal-seam and the superincumbent beds of shale and sandstone dip to the east under the sea of Robeson Channel at an angle of about 10°. These beds are cut through by a stream which has formed a deep gully, wherein the strata are laid bare; whilst at different points on the upper strata rest beds of fine mud and glacial drift, which contain well-preserved shells of marine Mollusca (*Saxicava rugosa*, *Astarte borealis*, &c.) now found in the neighbouring sea. This glacial marine deposit is met with up to a height of 1000 feet above the present sea-level, and shows that the land was sunk beneath the surface of the sea subsequently to the deposition of the lignite and plant-bearing shales, but was again elevated more than 1000 feet. Very probably the lignite-bed and the accompanying plant-bearing shales are to be met with in other parts of Grinnell Land, although hitherto only proved to occur at the place indicated.

Captain Feilden only made two visits, as the plant-bearing nature of the deposit was not discovered until a very late period of the Expedition. This is much to be deplored, as the shales enclose rich botanical treasures.

Captain Feilden's collection contains 26 species; and of these, 18 species are known from the Miocene deposits of the Arctic zone. This deposit is therefore doubtless Miocene. It shares 17 species with Spitzbergen (latitude 76°–79° N.) and 8 species with Greenland (latitude 70°–71° N.). The Grinnell-Land flora consequently more closely approaches the Miocene of Northern Spitzbergen (which lies from 3° to 4° of latitude further south) than that of Greenland (situated almost 11° further south). With the Miocene flora of Europe it has 6 species in common, with that of America (Alaska and Canada) 4, and with that of Asia (Sachalin) 4 also.

Let us now examine these plants somewhat more closely. Of Cryptogamia we find only a couple of *Equiseta*, of which one species is *Equisetum arcticum*, which is found not uncommonly in King's Bay, at Spitzbergen (see my 'Flora foss. Arct.' ii. p. 31). It flourished probably, like its nearest ally *Equisetum limosum*, Linn., on the muddy shore of a sea or a river. In Grinnell Land as in Spitzbergen, the Coniferæ hold the first place. Ten species of these occur, belonging to four families—Taxineæ, Cupressineæ, Taxodieæ, and Abietineæ. The Taxineæ are represented by the remarkable genus *Torellia*, of which the species *Torellia rigida*, Heer, must have been very abundant. This was previously known only from Cape Staratschin in Spitzbergen, where only a few fragments of leaves were found; now from Grinnell Land we have a great number of perfectly preserved leaves, which confirm the conclusions previously arrived at. It is, in fact, a conifer most nearly allied to the genera *Phœnicopsis* and *Baiera* of earlier periods. The leaves have the same form and texture as those of the *Phœnicopsis* of the Brown Jura (Oolitic); they are also traversed by numerous longitudinal nerves, and arranged in clusters. They differ, however, in having a channel enclosed by a rib. As the *Phœnicopsis* of the Jura forms a link with the *Cordaites* of the Carboniferous, so, on the other hand, it joins the *Torellia* of the Tertiary. This genus, however, is confined to the most northern portions of the globe. Amongst living Coniferæ *Podocarpus* (group *Nageia*), which genus was united by Parlatore with the Taxineæ, should stand next to *Torellia*.

The Cupressineæ are represented in Grinnell Land only by a *Thuites* (*T. Ehrenswärdi*, Heer ?), fine twigs of which were found in King's Bay, Spitzbergen (lat. 79° N.), but has only reached us from Grinnell Land in the form of one small fragment which cannot be determined with perfect certainty. On the other hand, the leaf-covered twigs of *Taxodium distichum miocœnum*, which is one of the most abundant plants of Grinnell Land, and appears in many varieties, are most beautifully preserved. Fortunately we have it in a state of bloom from this place as from Cape Staratschin, viz. the male flowers, which completely correspond with those of Spitzbergen. They show that this remarkable tree, now existing only in the south of the United States and in Mexico, lived and bloomed during the Miocene period almost as far north as 82°!

In Grinnell Land, as in Spitzbergen, the genus *Pinus* possesses the greatest number of species. These belong to 4 subgenera: 2 species belong to the Pines (*Pinus* in the strict sense of the word), 1 to the Spruce Firs, 1 to the Pitch-pine, and 1 to the *Tsuga* group. Of the Pines one species (*Pinus Feildeniana*, Heer), is represented by well-preserved seeds and by remains of needles which are very slender. This species is closely allied to *Pinus strobus*, L., and may be compared among fossil species to *P. stenoptera*, Heer, from Spitzbergen, and to *P. thulensis*, Steenstrup, from Iceland. *Pinus polaris*, Heer, is a second species, the needles of which are abundant. These needles are also known from Spitzbergen and Greenland. Excellently-preserved seeds of this species were discovered by Nordenskiöld in Spitzbergen.

It is a very interesting fact that in Grinnell Land two twigs of the Spruce (*Pinus abies*, Linn.) still covered with leaves were found. I had already received single detached leaves from Spitzbergen; with them there were seeds of this species, and, further, there was also found a scale of the cone (see my "Miocene Flora of Spitzbergen" in the 'Flora foss. Arctica,' ii. tab. v. fig. 35–49); so that the species could be determined with perfect certainty. We therefore see that our Spruce (Red Fir) was living during the Miocene period in Grinnell Land as well as in North Spitzbergen, and at that time doubtless extended as far as the pole, at least if any dry land then existed there. In Europe the tree did not then exist; hence very probably it had its original home in the extreme north, and has thence extended southwards. We first meet it in Europe in the Forest-bed of the Norfolk coast, and in the interglacial deposits of lignites in Switzerland. At that time, therefore, it had come into our regions, and has ever since formed a principal constituent of our forests. Its extreme northern limit is now in Scandinavia, latitude $69\frac{1}{2}°$ N.; and it is now spread over about 25 degrees of latitude, whilst during the Miocene period it was limited to the Arctic zone. The case is quite different with *Taxodium distichum*, the second species of tree which Miocene Grinnell Land had in common with the flora of the present day; for during the Miocene period it extended from Central Italy up to 82° N., and was spread over all portions of the northern hemisphere, whilst at present it is confined to a comparatively small area.

Tsuga forms a third subgenus of *Pinus* occurring in Grinnell Land, to which we must refer the *Pinus Dicksoniana*, Heer; small twigs covered with leaves, and one seed, were found, as at Cape Staratschin. The species resembles the American Hemlock-Spruce (*P. canadensis*). To these must be added some large needles which seem to indicate a Fir of the group of *Pinus grandis* and *P. lasiocarpa*.

The Monocotyledons are represented in Grinnell Land by reeds and fragments of leaves belonging to *Phragmites œningensis*, a species which has also reached us from Greenland and Spitzbergen, and shows that the damp localities were covered with large reeds; narrow leaves with a midrib, which lie along with them, indicate a *Carex* (*C. noursoakensis*, Heer), with which we are also acquainted from Greenland and Spitzbergen.

Of Dicotyledons Captain Feilden's collection contains 8 species belonging to 6 families—Salicineæ, Betulaceæ, Cupuliferæ, Ulmaceæ, Caprifoliaceæ, and Nymphæaceæ.

The Arctic Poplar (*Populus arctica*, Heer) is an old acquaintance, which one can trace over the whole Arctic zone, and which is one of its most abundant trees; of the two species of Birch, one (*Betula prisca*) is also abundant in high northern latitudes; and the occurrence of a pretty large piece of bark in Grinnell Land, and of a still larger piece in Spitzbergen, shows that the species formed trees of considerable size.

The second species of Birch from Grinnell Land (*Betula Brongniarti*, Ett.) is the only European species of plant from Grinnell Land which was not previously known from the Arctic zone.

The most abundant foliage-leaves of Grinnell Land belong to *Corylus MacQuarrii*, Forb., sp., which is spread over the whole Arctic zone and is nearly related to the living *C. avellana*, L. Very beautiful leaves of *C. insignis*, Heer, occur; this species I have also received from Greenland; and in the form of its leaf it resembles the American Hazel. An Elm (*Ulmus borealis*, Heer) is represented by a couple of leaves and a fruit, and a Viburnum (*V. Nordenskiöldi*) by several fragments of leaves. Both species are also known from Spitzbergen.

These trees and shrubs doubtless lived on the land, and covered the plains and hills of this far northern region with green; but that there also existed stagnant water is shown by a water-Lily (*Nymphæa arctica*, Heer) of which the rhizoma, exactly agreeing with one from the Ice-fiord, Spitzbergen, was found. Here the leaves and fruit could also be identified (see 'Flora Arctica,' ii. tab. xiv. figs. 1, 2, 6, 7).

The thick lignite bed of Grinnell Land would indicate a large peat-moss, in which most probably a small lake existed. On the shallow bottom of this lake the great rhizomes of the Water-Lilies might spread; and from them the leaves would rise to the surface of the water. On the muddy shore stood the large reeds and the sedges (*Carices*), the Birches and the Poplars, the *Taxodia* with their graceful foliage, and the rigid-leaved *Torelliæ*. The drier spots and neighbouring chains of hills were probably occupied by the Polar and Feilden Pines (*P. polaris* and *P. Feildeniana*), by the Firs, the Hemlocks, and the Hayes-Spruce (*Pinus Dicksoniana* and *P. Hayesiana*). To these must be added the Elm and the Hazel bushes, whose fresh green foliage will have served to break the gloomy garb of the Pine-forest. This forest was no doubt inhabited by animals; yet hitherto only the elytron of a Beetle (*Carabites Feildenianus*, Heer) has been discovered lying with the plants. A further careful investigation of this important locality would no doubt produce more such remains, and also promise a further rich result in plants.

In the lignite itself we may expect to find the teeth and bones of vertebrate animals.

If we glance back at the facts communicated, we shall find that they confirm and extend the earlier results in a most satisfactory manner. As was to be expected, during the Miocene period there appear in this most northern portion of the earth, for the most part, the same species, with which we are already acquainted from Spitzbergen and Greenland; and it is highly probable that the same flora extended up to the Pole, and that, supposing dry land to have existed there, this latter was clothed with the same forest of coniferous and leafy trees.

That the flora of Grinnell Land approaches much more closely to that of Spitzbergen than to that of Greenland, is easily intelligible from the greater difference of latitude. The plant-bearing locality of Grinnell Land lies much nearer to the north-west of Spitzbergen (Ice-fiord and King's Bay) than to Disco and the opposite peninsula of Noursoak, which have furnished the Miocene plants of Greenland.

We have previously pointed out ('Flora foss. Arctica,' ii. p. 16) that the Miocene flora of Spitzbergen as compared with that of Greenland would seem to indicate a considerable climatic difference, inasmuch as a great number of more southern forms which Greenland possesses—such as *Castanea*, evergreen *Magnoliæ*, *Prunus, Ilex*, *MacClintockia*, and *Coccolites*—are wanting in Spitzbergen. The same holds good with regard to Grinnell Land.

On the other hand, the facts hitherto brought forward indicate no difference between Spitzbergen and the plant-bearing locality of Grinnell Land, lying from 3 to 4 degrees of latitude further north. It is true that the Miocene flora of Spitzbergen is very much richer, since we are already acquainted with 179 species belonging to it. This, however, is probably due to the fact that Professor Nordenskiöld and his comrades collected in Spitzbergen with great zeal and success during several expeditions, whilst the plant-bearing locality of Grinnell Land was only visited by members of the English Expedition on a few occasions. It is to be particularly noted that *Taxodium distichum* and a Water-Lily still appear in this place. The latter presupposes fresh water, which must have remained open during a great part of the year; and the *Taxodium* excludes an Arctic climate. Indeed it only exists still in North Germany by cultivation, and Professor Schübeler's repeated attempts to cultivate it at Christiania were in vain (comp. 'Pflanzenwelt Norwegens' by Schübeler p. 148). Representatives of plants now living exclusively in the Arctic zone are wanting among the species of Grinnell Land; but, on the other hand, certainly most of the genera still extend into the Arctic zone, viz. *Equisetum*, *Pinus*, *Phragmites*, *Carex*, *Populus*, *Betula*, *Corylus*, *Ulmus*, and *Nymphæa*. Of these, however, only *Equisetum*, *Carex*, and *Populus* extend beyond latitude 70° N.; the remaining genera cease earlier. *Pinus abies*, L., reaches latitude 69° 30′ N.; the genus *Phragmites,* in *P. communis*, in Finmark, to latitude 69° 45′ N.; *Corylus*, in *C. avellana*, to latitude 67° 56′ N.; *Ulmus,* in *U. montana*, in Norway, to latitude 66° 59′ N., and cultivated to nearly latitude 70° N.; *Nymphæa*, in *N. alba*, in Scandinavia, to latitude 69° 11′ N. These genera therefore appear in Grinnell Land at from 12 to 15 degrees higher latitude.

P.S., 20th Jan., 1878.—Mr. Edward Moss, Surgeon of H.M.S. 'Alert,' collected some fossil plants in the same spot as Captain Feilden, and has submitted them to Prof. Heer's examination. They belong to 14 species, 4 of which are wanting in Captain Feilden's collection. We therefore know at present 30 species of Miocene plants from Grinnell Land. Descriptions and figures of all the species will be published in the fifth volume of the 'Flora fossilis arctica.'

Discussion.

The President, after expressing his sense of the value of Prof. Heer's paper, referred to the great difficulties under which Capt. Feilden laboured during his visit to the Arctic region, and remarked that nevertheless he had realized results of very considerable importance. He referred to Prof. Heer's notion that a migration of certain plants had taken place since Miocene times from north to south, and pointed out that the existing North-American flora more resembles the Miocene than its own Pliocene flora. An examination of the Echinodermata brought home by the Arctic Expedition had led him and Mr. Sladen to the belief that these also furnish indications of there being a polar zone of Echinoderms.

Capt. Feilden exhibited a photograph and gave some account of the locality from which the plant-remains were brought. He stated that shales and sandstones similar to those overlying the lignites were found lying directly on the older schists in other neighbouring valleys, and that in some instances fragments of lignite occurred in them, and suggested that probably the whole of the valleys here were at one time occupied by deposits of the same age.

Prof. Ramsay remarked that after listening to all that had been done in the investigation of Arctic floras, it was impossible not to feel convinced that we only require to get hold of the right clue in order to make out a great deal. He said that he could not believe that plants such as Sequoias, Figs, and Vines could live through the long night of an Arctic winter and flourish again the following summer. He thought that the gradual accumulation of palæontological facts was gradually leading to a general opinion that there must have been a change in the direction of the axis of the earth with respect to the sun's light; and if, as he understood, Prof. Heer believed that plants had spread from north to south, it seemed to him that this was strongly in favour of a change in the direction of the polar axis.

Mr. Evans said that Capt. Feilden had referred to a dying-out of species as we advance towards the pole, and suggested that if this be real, it may be due to our explorations northwards lying in the same direction as that taken by the pole in its movement southward. The variation of level mentioned to the extent of 1000 feet, might throw some light on the question, as it might be due to a change in the position of the nucleus of the earth with regard to its surroundings.

Capt. Sir George Nares referred to the presence of vast fluviatile deposits close to the bed of lignite.

Dr. Murie thought that too much stress was laid upon the influence of the sun's light in this question, and referred to the fact that tropical plants are preserved and flourish in St. Petersburg in spite of the long dark winter. He suggested that changes in electrical conditions might have some influence on the possibility of the existence of life at the poles.

Prof. Hughes inquired how far round the arctic circle we can find evidences of such changes as are assumed. If the changes in the position of the pole were geographical, it was clear that the Miocene vegetation could not approach the pole all round at the same time.

Mr. Woodward remarked that the *onus probandi* rested, not with the geologists, but with the mathematicians, upon whom it was incumbent to show how plants could grow at the points where their remains were found, supposing the position of the earth to have remained the same.

Mr. Sollas remarked that Prof. Heer had already shown that the Miocene flora diminished both in genera and species when traced from Switzerland northward, in such a manner as to indicate that while the temperature of the northern hemisphere was generally higher in Miocene times, yet it decreased towards the north pole very much as it does now, only more slowly. Capt. Feilden's remarks on the thinning-out of species from Spitzbergen to Grinnell Land were quite in accordance with this. It thus certainly appeared to him that it was not the geographical position of the poles, but the climatal conditions of the polar regions which had undergone a change. As regards a higher temperature, Dr. Croll's theory would account for that. As regards the necessity for light, it seemed to him that a long winter merely meant for the arctic plants a longer sleep. The light of a short summer would reach the ground unaffected by the absorptive action of aqueous vapour, which would filter out a good deal of the non-luminous heat-rays. In high northern latitudes heated by warm currents of water, we should have produced during the Miocene times natural conditions very similar to those produced artificially in the greenhouse of St. Petersburg: aqueous vapours would furnish a very efficient substitute for glass; and oceanic currents would serve for a warming-apparatus.

7. *On* Points *of* Similarity *between* Zeolitic *and* Siliceous Incrustations *of* recent Formation *by* Thermal Springs, *and those observed in* Amygdaloids *and other* altered Volcanic Rocks. By Prof. A. Daubrée, F.M.G.S. (Read June 20, 1877.)

[Plate IV.]

The production of zeolitic minerals by the agency of thermal waters is not, as might at first sight have been supposed, a merely accidental circumstance confined to a particular locality, but appears to be tolerably general in many places—and is therefore of particular interest, not merely as illustrating the changes that have gone on at the springs themselves, but as furnishing a clue to the origin of many of the components of erupted rocks, and more especially of altered volcanic rocks.

I. *Zeolites and allied minerals produced by Thermal Springs.*

The locality where these minerals were first observed as deposits from hot springs is Plombières * (Vosges); and subsequently I have discovered them under similar conditions in Roman masonry at Luxeuil † (Haute-Saône), at Bourbonne (Haute-Marne), and in the neighbourhood of Oran in Algeria. At all these places the mouths of the thermal springs, when first utilized for baths during the Roman occupation, were surrounded by works in concrete formed of fragments of brick and stone, both sandstone and limestone, united by lime mortar. When, in the progress of recent works, it became necessary to cut into these masses of ancient masonry, it has been found that certain portions of them have, under the action of the mineral-water, undergone changes of a very remarkable kind, both in a chemical and mineralogical point of view, and of the following character ‡.

In the vesicular cavities of the bricks new minerals are prominently developed, being principally zeolites, among the most abundant of which is chabasite in limpid crystals having the form of a rhombohedron approximating to a cube, which are striated parallel to the edges, and at times appear in the macles common to the species. The measurement of the angles, as well as chemical analysis, show no differences from the natural mineral. Phillipsite or lime harmotome is similarly found accompanying the preceding species—an association exactly analogous to that observed in the amygdaloidal trap rocks of the west of Iceland by M. Descloizeaux §.

In the hollows of the calcareous cement, small crystals of apophyllite are found which correspond to the natural mineral in form and composition, even to giving traces of fluorine when heated in a

* Comptes Rendus, xlvi. pp. 1086, 1201 (1858).
† Ann. des Mines, 5th series, vol. xiii. p. 227.
‡ Bull. de la Soc. Géol., 2nd series, vol. xvi. p. 502, xii. p. 562, xviii. p. 108.
§ Ann. des Mines, 4th series, vol. xii. p. 373.

glass tube. Among the other substances of the same nature are various minerals, which have not been perfectly identified—the principal ones being small globules studded with microscopic crystals, which are apparently gismondine, a mineral found under similar conditions in the scoriaceous lavas of Capo di Bove near Rome, and crystalline needles having the appearance and chemical characters of scolecite.

At Plombières the zeolites are accompanied by translucent and colourless opal or hyalite in considerable quantity; and at the same place a gelatinous deposit was found upon parts of the masonry receiving the full flow of the hot water, which was also transparent and colourless when collected, but became opaque and snow-white in drying, forming mamillated masses of a fibrous structure like other concretionary minerals, which melted with intumescence before the blowpipe, and gelatinized with acids. This is a hydrated silicate of lime without alkali, analogous to okenite, a mineral found in amygdaloidal rocks in Ferro, Iceland, and Greenland. It has not been possible, however, to determine its composition exactly, owing to the fact of its being intimately mixed with opal and hydrated silica.

Aragonite is occasionally seen in very acute double six-sided pyramids of the form called apotome by Haüy, with the face e^1, and resembling the crystals found in iron-ore deposits, and in some basalts; but it is more commonly found in acicular crystals.

Calcite occurs in many of the cavities associated with chabasite, as in the Iceland lavas. The crystals are of many forms; both scalenohedra with rhombohedral terminations ($d\frac{6}{5}$) and rhombohedra have been observed. In some white or occasionally violet-coloured deposits obtained at Plombières I have found fluor-spar both in the pulverulent form and in microscopic crystals. These are often found in the neighbourhood of apophyllite crystals which also contain fluorine.

In addition to the above minerals the hydrated silicate of alumina known as halloysite has been found at Plombières, the principal seat of this mineral being, however, in the fluor-spar veins from which the hot springs rise.

In addition to the geodes of crystals visible to the naked eye, the paste or substance of the bricks has undergone a change, the nature of which has been determined both by the aid of the microscope and by chemical analysis. This change however, is, apparent at sight when a brick which has undergone alteration is compared with others of the same period that have not been subjected to the action of the spring. While the latter are generally imperfectly burnt and friable, those included in the concrete are often hard, very compact, and sonorous, recalling the texture of phonolite, and break into thin acicular and trenchant fragments under the hammer.

The microscopic examination of these bricks shows that their substance is intimately impregnated with different minerals even at points entirely removed from the infiltration visible to the naked eye. For the purpose of studying these changes, transparent sections of an unaltered brick were prepared as terms of comparison, the results of this preliminary examination being contained in Note 2 (p. 83).

In the altered bricks the cavities, instead of remaining empty, are irregularly filled with colourless and transparent substances which are without doubt due to the slow and prolonged action of the heated water to which they have been subjected (Pl. IV.).

The following are the principal substances that I have observed in the pores of the bricks:—

1. Chabasite in cube-like rhombohedra without cleavages, about 0·08 m.m. in the side.

2. Prisms disseminated through the paste, which are possibly christianite* (phillipsite).

3. Mesotype, recognizable by the crystalline forms, which are prisms with basal terminations and grouped radially (fig. 3). They have a decided action upon polarized light, and when subjected to the action of acid leave as a residue prisms of the same form, which have no action upon polarized light, and are probably siliceous skeletons of the original crystals; the leading dimensions are 0·1 m.m. long and 0·02 m.m. broad. This method of occurrence is exactly similar to that observed in the pores of certain basalts, a specimen from Donnersberg in Bohemia offering a striking example of this resemblance.

4. Substances in mamillated concretions concentrically banded, which are not attacked by acids, scratch felspar, and have no action on polarized light. These are probably opal, of the variety known as hyalite.

5. Hexagonal plates with rounded angles aggregated in the manner usually observed in tridymite, to which species they probably belong, as they are insoluble in acids.

6. Fibrous radiated spherules, having a powerful action upon polarized light and giving a fixed black cross when rotated between crossed nicols, or the optical properties characteristic of chalcedony, which substance they further resemble in being harder than felspar and unaffected by acids. Occasionally these globules are arranged along the walls of the cavities in the form of contiguous hemispheres, their maximum diameter being 0·02 m.m.

7. In addition to the fibrous spherules, others of smaller size are found distributed through a colourless transparent and optically inactive substance, which is opal. These globules have a feeble action upon polarized light, like that of gummy substances, and are often arranged along the sides of a cavity, forming a kind of border, in a manner exactly similar to that observed in certain rhyolites, as, for example, those of Nisiros, and of Telkybania in Hungary.

8. Upon one specimen globules resembling those last noticed have been observed, which have a yellowish tint, and are attacked by nitric acid at a temperature as low as 30° C., which characters are analogous to those of the globules of similar appearance usually found in palagonite.

9. Calcite is often found completely filling the cavities, with the

* Christianite is used throughout as synonymous with phillipsite, and is not to be mistaken for the variety of anorthite known by the same name.

form of the primary rhombohedron, reproducing an arrangement found in the basalt previously noticed from Donnersberg. In other cases it is intimately associated with opal and affects the form of an acute rhombohedron.

The different substances noticed above occur as partially or totally filling microscopic cavities of different forms, these being sometimes rounded, like the larger vesicles, and sometimes elongated into fine cracks. Usually the concretionary substances penetrate the substance of the brick to a certain depth from the walls of the cavity, forming a kind of penumbra.

The arrangement of these different substances, which I have examined with the assistance of M. Fouqué, are represented in the drawings (Pl. IV.), for which I am indebted to the skill of M. Thoulet.

The presence of chalcedonic quartz in association with opal is a fact worthy of attention, as proving that silica may be deposited in the anhydrous form, although the temperature of the medium in which the separation took place did not exceed 70° C. The production of quartz at such a low temperature has not, I believe, been previously noticed.

By chemical examination I have not less certainly proved that the different minerals are the results of the introduction of foreign substances into the body of the brick. The penetration is nowhere uniform, and may vary very considerably in the same fragment from the external surface to the interior. The former part is usually compact and contains up to 8 per cent. of water, so that it decrepitates violently when heated to redness, while the central and more porous part contains only 2 or 3 per cent. of water. There is a similar difference in the proportion of lime and potash contained in the two parts, these bases being found in larger quantity in the compact than in the porous bricks. The compact character of the outer portion of the bricks is therefore due to impregnation with hydrated silicates of lime and potash, and probably also of alumina, such as are found in the zeolitic family of minerals.

When finely powdered and heated with boiling distilled water, the bricks give a solution of silicate of potash having an alkaline reaction. A complete analysis, the results of which are given in Note 3 (pp. 83, 84), shows that the amount of zeolitic substance added to the bricks is from 13 to 14 per cent. of their total weight.

II. *The contemporary production of Zeolites and their associated minerals furnishes an experimental demonstration of the mode of formation of the same minerals in Amygdaloids and many other classes of altered volcanic rocks.*

The brickwork altered in the manner described in the preceding part, and Amygdaloids, as well as many other altered volcanic rocks, have many points of resemblance in the nature of the minerals developed by such changes. This similarity, or it may even be called identity, applies not only to the portions visible to the naked eye (zeolites, opal, aragonite, and other compounds), but extends to the minute microscopic pores. Such a complete reproduction of phenomena speaks for a common method of origin, which is confirmed by an examination of the method of occurrence considered as a whole.

Mode of Formation of Contemporary Zeolite.

From the circumstance of finding zeolites disseminated through the minutest cavities of the mass of old volcanic rocks, it was at one time supposed that these minerals were formed by segregation in the mass of the rock, and that they were enabled to retain water at a high temperature, under the influence of pressure. The results of subsequent observations, however, have led to the belief that the deposition of zeolites is a direct consequence of infiltration through the mass of the rock; but as, under ordinary conditions of laboratory experiment, these hydrated silicates could not be reproduced in the crystallized form, it was considered that a high degree of temperature and a pressure sufficient to prevent the escape of the water of crystallization, were elements essential to their production.

The above conjectures are untenable in the face of the facts previously set forth, which furnish, so to speak, an experimental demonstration of the method under which the phenomena in question have actually been produced.

The Roman masonry, although now of a very compact texture, was originally freely penetrable by water through its entire mass, on account of the essentially spongy character of the bricks when first laid; and, the absorbed water being forced to circulate by the pressure of the spring, the mass of masonry was not only surrounded but penetrated by the hot mineral water. A current, of feeble strength no doubt, but still continuous, being kept up, the perpetual renewal of the water, which contains only traces of saline matters, gave rise to the accumulation of deposits in notable quantity, by the accumulated action of a cause of low intensity, but continued for a considerable time. This is a condition difficult of attainment in laboratory experiments, when undertaken in imitation of natural processes; but its importance when applied to the explanation of different geological phenomena will be readily appreciated.

The heated mineral water, in virtue of its alkaline constituents, exerts a slow action upon certain of the substances encountered in passing through the brickwork, thereby producing zeolites. The action is not necessarily attended with solution, but probably in some cases is analogous to the process of cementation.

The essential elements, therefore, in the production of these minerals are—circulation of water, and chemical reactions consequent upon such circulation.

In order to produce crystallized zeolites, it is evident from the facts recorded above that a temperature of 60° or 70° C. is sufficient, at least for some of the more abundant species. It seems reasonable therefore to suppose that the formation of these minerals in rocks may take place under the ordinary atmospheric pressure, and at the surface of the ground; but it is not the less remarkable to find these minerals completely developed in form in the wet way at a temperature which is far below the point at which they are reputed to be soluble in water.

The nature of the minerals produced is very closely connected with variations in the composition of the containing material; thus the crystals of chabasite (a non-calcareous zeolite) are almost entirely confined to the bricks, while others are more abundant in the mortar, the same solution being capable of producing different minerals by its action upon rocks of different characters. This localization of typical zeolites seems therefore to prove that the constituents were not entirely introduced by the mineral-water, but that the lime, alumina, and other substances necessary to the constitution of the new compounds were furnished partly by the bricks and partly by the mortar, the chief constituents furnished by the mineral-water being the alkalies. The newly developed minerals are generally in close proximity to their points of formation, in which respect they differ from the greater part of the minerals found in metalliferous veins, which are often completely absent from the rocks forming the walls. It may be supposed, however, that water acting similarly at a higher temperature would exert a greater solvent power, and therefore that zeolites produced under such conditions might be susceptible of removal to a greater distance from their points of origin than in the case under discussion.

Importance of Zeolites and the associated Minerals as Secondary Products in Volcanic Rocks, especially in Amygdaloids and Conglomerates.

The fact that silicates of the zeolitic group are found under exactly similar conditions in the so-called amygdaloidal rocks in countries far removed from each other is well known to all mineralogists; and the same resemblance extends to rocks of different geological ages, such as the melaphyres and diabases of the Silurian, Permian, and Triassic periods, and the basalts of Tertiary times. The characters of these minerals lead to the conclusion that they have been developed in the vesicles and other cavities of the rock subsequently to its consolidation. The most widely distributed species of the group, stilbite, heulandite, chabasite, mesotype, analcime, and christianite, are found not only associated together in the same mass of rock, but often in the same cavity, following a recognizable order of succession.

It is usual to find other minerals in association with zeolites, which appear to have been developed under conditions but little different from those that have produced the latter. The most important of these associated minerals is quartz, in the various forms of agate, chalcedony, and crystallized quartz—others being opal, different kinds of chlorite, delessite, chalcedonite, and chlorophæite, green earth, lithomarge, steatite, clatholite, and epidote, together with calcite, aragonite, and siderite; and, lastly, among their rarer associates are vivianite, barytes, celestine, fluor-spar, native copper, &c.

Among the localities producing zeolites and their associated minerals the following may be mentioned:—

1. In basaltic rocks—Auvergne, the Siebengebirge, the Wetterau, the Kaiserstuhl in the Grand Duchy of Baden, the Mittelgebirge in Bohemia, the Euganean Hills and the neighbourhood of Rome, the Cyclopean Islands near Sicily, the Tertiary volcanic region of Antrim, and the west coast and islands of Scotland, Faroe, Iceland, parts of Greenland, and certain districts in India and Australia.

2. In the more ancient eruptive rocks, melaphyre and diabase—the Southern Tyrol, especially the Fassa-Thal, the neighbourhood of Oberstein and Idar in the Pfalz, Giromagny in the southern part of the Vosges, Nassau (in Schaalstein), the Harz (in Blätterstein), Thüringen, the Isère (in the variolite or spilite of Drac), Lake Superior, Nova Scotia, Connecticut, Central Africa, &c.

That these minerals are not to be considered mere adventitious accretions to the rocks containing them, is evident from the large proportion that the zeolitic kernels often assume in relation to the whole mass. Thus, according to Boué*, in the Isle of Skye stilbite is found at times in nests from 4 to 5 feet in diameter, and makes up a notable portion of the rock. The same thing is seen in the Cyclopean Islands, where analcime is found abundantly, both in nodules and in veins; as well as in Faroe, Iceland †, and other places. In addition to these voluminous masses, the same minerals are often sufficiently abundant in certain parts of the rocks to form an important proportion of their total bulk. Thus in the Wetterau, according to the observations of Tasche ‡, chabasite and christianite are present in the compact portions, in addition to filling the cavities, of the basalts; and these minerals can generally be recognized in thin slices of these rocks, when examined by the microscope, as, for example, in the basalt of Donnersberg and other localities in Bohemia.

The minerals associated with zeolites may also form important elements in the constitution of the class of rocks under discussion. In evidence of this we have the fact, recorded by Boussingault, that the crystalline rocks of the Andes, with very few exceptions, contain carbonates, as shown by their effervescence when treated with acid. The spilites of Drac || in the same way lose 10 per cent. by weight when finely powdered and heated with a weak acid, lime with a little magnesia and iron being found in the solution. At Obercastel, near Bonn, siderite is found in basalt, not only filling geodes but forming part of the paste or substance of the rock, where it is associated with a considerable proportion of zeolites; and similar conditions of association are recorded in the basalts of other parts of the Siebengebirge and of the Wetterau §.

The minerals chlorite and green earth, which have been proved both by microscopic and chemical investigation to form component parts of many of the so-called basic rocks, appear also to be the result of decomposition, as some of the mineral constituents of the latter, more

* Écosse, pp. 238–245. † Sartorius von Waltershausen.

‡ Schotten, pp. 52–57.

|| Gaymard, Ann. des Mines, 4e sér. vol. xviii.; Lory, 'Isère,' p. 136.

§ Von Dechen, 'Siebengebirge,' 2nd ed. p. 149. Mitteldeutsche geol. Karte, descriptions: Schotten, pp. 52–57; Alsfeld, p. 51; Lauterbach, p. 64.

especially hornblende and augite, are found at times to be transformed into a chloritic substance without change of their original crystalline form. Such chlorite is therefore of similar origin to that found in company with zeolites and carbonates in the geodes. The same is true of the spilite of Drac, in which chlorite, green earth, and carbonate of lime form a great part of the mass of the rock. The hyperite amygdaloid of Nassau*, contains more than one fifth of its weight of each of these minerals; and the melaphyre of Lake Superior is another example of a similar association, one specimen having been found to contain 46 per cent. of delessite.

Water up to 3 or 4 per cent. appears also to be a common constituent of the mass of such rocks when containing carbonates. Delesse found 3 per cent. in the melaphyres of Oberstein †.

Demonstration of the Origin of Zeolites and associated Minerals in Volcanic Rocks.

The phenomena that we have previously demonstrated to be caused by the action of thermal mineral-waters, has in former times been developed to a very considerable extent in certain geological formations. The rocks in which zeolites are found, have been permeated for a longer or shorter period by heated water, which, reacting upon their constituents, has given rise gradually to various species of minerals.

As is the case at the present day, these eruptive rocks may have been the seat of emanation of water at high temperature, which, coming from great depths, penetrated the rocks at or near the surface in the manner seen in the lavas of modern date.

In addition to the above, it may be admitted that these essentially permeable volcanic masses were readily accessible to rain and other surface-water; such an introduction of water in rocks of this vesicular character is not only possible, but, so to speak, necessary, circulation being effected by the innumerable cavities in the same way—in brief, as by a system of drain-pipes.

Water so infiltrated before the rock had completely cooled would of necessity become rapidly heated; and with every increment of heat the solvent and decomposing power exerted on the surrounding rock would be increased. But whether of superficial or deep-seated origin, the action of the heated water would be similar to that of the thermal spring upon the masonry—the effect first being that of decomposition, and subsequently of reconstruction with the formation of new compounds.

Zeolitic minerals may therefore be considered a kind of "extract" of the rocks so subjected to continued lixiviation—a view that is borne out by the more or less altered condition usually observed in the rocks most abounding in this class of mineral—the alteration in many cases having resulted in the production of an earthy state, forming the so-called wacke of the older geologists; and chemical examination proves that in such cases the rocks are hydrated.

* Ludwig, Section Gladbach, description, pp. 103–108.
† Ann. des Mines, 4e sér. vol. xvi. p. 511.

The deposits of agates, chalcedony, and other varieties of quartz in volcanic rocks may be explained as the result of similar causes to those producing these minerals by contemporary formation. These rocks do not contain quartz or free silica as original components, but have produced them as a consequence of their own alteration, in the same manner as the opal and chalcedony formed in the concrete of Plombières, or as in the more striking case of the alteration of glass when exposed to superheated water, whereby crystals of quartz and diopside-augite are formed*.

Siliceous infiltrations are found in many volcanic rocks of an intermediate percentage of silica (rocks of the trachydoleritic class), as for example in Auvergne, at Santorin, Aden, St. Paul and Amsterdam Islands. In the so-called acid (trachytic) rocks these infiltrations are occasionally so abundant that they become essentially quartzose, passing into the condition of burr stones. Examples of this kind of silicification are found in the trachytic tuffs of Tokay and Hlinik, in Hungary, where the rocks, at times kaolinized, are intermingled with quartz of different kinds, chert, amethyst, &c., forming the so-called "porphyre molaire" of Beudant, and the hydro-quartzite of Szabo, as well as various kinds of opal, including the precious or noble opal which is worked for jewellery†. Similar facts are observed in the island of Milo, where the millstone rocks containing opal and gelatinous silica are associated with cimolite and alunite. Chlorite and green earth are other minerals occurring in this class of rocks, which appear to be due to the same kind of action.

Simultaneously with the production of green earth, quartz, and other forms of free silica from the rock, by decomposition of its constituent silicates the metallic bases of the latter, lime, magnesia, and ferrous oxide, are reproduced as carbonates, forming the minerals calcite, dolomite, and siderite, which, when present in such rocks, have evidently been formed by the wet way.

A very significant grouping, as regards the latter minerals, is observed in the Roman masonry previously described, where we find opal, sometimes in voluminous concretions, and less frequently chalcedonic quartz with lithomarge, calcite, aragonite, vivianite, and fluor-spar.

Zeolites are not exclusively confined to volcanic rocks, being also found in certain metalliferous deposits, such as the silver-lead-ore veins of Andreasberg, in the Harz, those of Kongsberg, in Norway, and the reticulated groups of veins of the Banat. A very remarkable instance of this class of association is afforded by the cupriferous deposits of Lake Superior, where native copper is often disseminated in prehnite, analcime, and other zeolites, as well as in calcite, in such a manner as to show that the production of both kinds of minerals has gone on under substantially similar conditions.

The reason of the intimate association of compounds of such com-

* Daubrée, Mém. de l'Acad. des Sciences, 1860, vol. xvii.; Ann. des Mines, 5e sér. vol. xvi. (1860) pp. 155, 193.

† Szabo, 'Trachyt &c. der Umgebung Tokay;' Naumann, 'Geognosie,' vol. p. 618.

pletely dissimilar chemical constitution is furnished by the phenomena witnessed at Bourbonne, where the zeolites have been deposited side by side with fahlerz (tetrahedrite), copper pyrites, and other usual constituents of metalliferous veins, by one and the same water at one and the same temperature, according to the nature of the material presented to its action. A further point of resemblance is furnished by the crystals of calcite accompanying the zeolites in the deposits of the springs, which affect varieties of forms exactly analogous to those observed in mineral veins.

Among the more remarkable localities where zeolites have been found, is the lignite of Kerguelen's Island, according to the analysis given by Percy*. This lignite is known to be of Tertiary age, and is associated with volcanic rocks.

In conclusion, the argument presented in the preceding pages may be summarized as follows:—The production of zeolites and their associated minerals by the action of thermal springs is not confined to the formation of crystals lining the visible cavities of the bricks, but has extended to the compacter portions, the same minerals being found in the smallest cavities, when examined by hand-lens or microscope, which latter method of investigation had not been applied previously to the present communication. The bricks so altered, present many remarkable points of resemblance to certain volcanic rocks of compact and tufaceous structure, both as regards the nature and the arrangement of the substances deposited. The siliceous products in the bricks recall the (so-called) acid rocks, while the zeolites and palagonite globules in the same way remind us of the (so-called) basic rocks. These significant resemblances extend to the minutest particulars; so that even the most experienced mineralogist might mistake these for natural products if the unaltered portions did not betray their artificial origin.

These relations of similarity and even of identity between the natural and artificial products evidently justify us in assigning a common or analogous mode of formation to both. Now, the conditions under which the contemporary formation of zeolites accompanied by opal, chalcedony and carbonates proceeds are perfectly ascertained; we have, so to speak, presented to us in the products of these thermal springs the results of a series of experiments of the most instructive character, continued through a period of several centuries; and that similar agents have been at work in the production of similar minerals by the alteration of erupted masses of rock, cannot reasonably be doubted.

In addition, however, to the class of rocks whose alteration forms the subject of the present communication, I may remark that there are others that have been transformed by similar agencies, but more completely, such as palagonite, which, as is well known, is a hydrated volcanic tuff in which concretionary masses of a peculiar kind replace the crystals contained in the rock when in the unaltered condition. Serpentine is probably another instance, the rock known by this name being most likely the hydrated condition of masses which, in their

* Metallurgy, vol. i. p. 318 (1875).

normal state, consisted essentially of olivine. The hydration of perlitic rocks, and the hydrated concretions incrusting their cavities, may also be due to analogous causes. These latter rocks may be considered as results of the more or less advanced effects of alteration by aqueous agency.

Note 1.—It is necessary to add that these modifications in the nature of the brick have not been uniformly effected. It is not uncommon to find in the same specimen a friable and earthy interior combined with a compact and altered exterior; but however irregular the fragment may be, the change has gone on from the surface to a tolerably uniform depth, and in concentric bands analogous to the structure observed in nodules of jasper. This latter circumstance shows very plainly that the compact parts of the fragments are the result of modifications to which they have been subjected since they were imbedded in the concrete.

Note 2.—This brick is composed of an amorphous transparent substance, colourless or of a pale yellow tint, with innumerable cavities, through which are disseminated granules of a ferruginous silicate of a bright red colour, due to ferric oxide. Grains of quartz are also common, generally broken and irregular in outline, as well as particles of quartzose sandstone. A single crystal of triclinic felspar has been seen, besides numerous small colourless laminæ, which darken under crossed Nicols in the direction of the longer axes, and which are probably crystals of mica seen in section. The quartz contains numerous cavities; but none of these contain liquids, which may be due to the high temperature to which the brick has been exposed in the kiln. A fluxion structure is tolerably constant, as evidenced by the alignment of the red granules, the quartz grains, and the scales of mica, which follow the same general direction.

Note 3. *Chemical Examination.*—The substance of the bricks, averaged by sampling several specimens which were apparently compact when seen by the naked eye, was subjected to analysis by M. Fouqué, with the following results as obtained from two samples.

Brick A. This is of a uniform red substance, excepting a few interspersed grains of quartz. It lost 4·32 per cent. in weight by heating in a sand bath to 120° C.; when calcined at a bright red heat a further loss was experienced of 5·22 per cent. There was only a very slight effervescence with acids.

When heated with boiling distilled water, 10 grammes of the finely powdered material gave an alkaline solution, which neutralized 8 milligrammes of monohydrated sulphuric acid, contained only traces of alkaline carbonates, and was free from lime. When acidified and evaporated to dryness, a residue insoluble in acids was obtained, proving the soluble alkaline constituent to be a silicate of potash.

Brick B.—This was generally similar in physical character to sample A. The loss of weight was 5·5 per cent. at 120° C., and an additional 6 per cent. by calcination. It contained no carbonates; and the solution extracted by water neutralized 9 milligrammes of sulphuric acid. Another portion, weighing 10 grammes, was treated for 15 minutes with boiling nitric acid diluted with 5 times its volume of water, the results being as follows:—

	Brick A.	Brick B.
Soluble portion	1·397	1·488
Insoluble portion	8·603	8·512
Together	10·000	10·000

Analyses of the soluble portion—

Silica	19·39	8·85
Alumina	17·33	19·73
Ferric oxide..............	5·37	5·95
Lime.....................	51·40	60·34
Magnesia	0·75	0·47
Potash	5·94	5·07
Soda.....................	0·33	0·13
Total	100·51	100·54

The large percentage of potash in the bricks containing zeolites is remarkable. For although it is well known that this alkali is an invariable constituent of clays, the bricks of Plombières contain it not only in larger amount than is found in natural clays, but in such a condition as to be rendered readily soluble by weak acids, which is not the case with the alkalies contained in clays. It appears therefore to be due, in part at any rate, to the alkaline constituent of the thermal water. Possibly the potash found in green earth, where that substance replaces crystals of pyroxene, as in the Tyrol and elsewhere, may be derived from a similar source.

Note 4. *On the crystalline forms of chabasite and christianite of contemporary formation.*—The chabasite is in rhombohedra, which are partly simple and partly macled in the same manner as natural crystals.

The christianite of Plombières appears to be identical in form with the crystals found at Marburg and Somma; *i.e.* they are cruciform penetration-twins of two individuals not showing any re-entering angles. According to M. Descloizeaux, the plane of the optic axes is parallel to the macropinakoid, and their first median line to the macrodiagonal. The primitive form is a rhombic prism of 111° 13′. The crystals from Oran appear, however, to be macled on the type of harmotome, and the optic axes to be similarly placed to those of that species, the primitive form being probably a rhomboidal prism of 128° 11′. The crystals are too small, however, to afford any very accurate measurement.

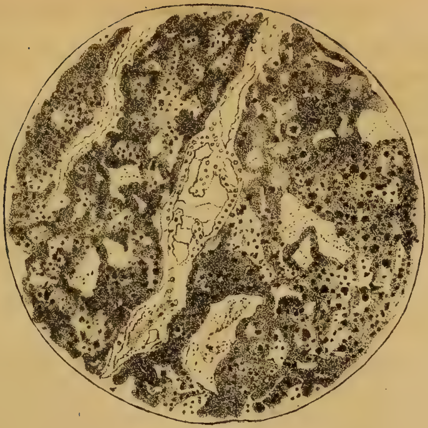


Fig. 1.
× 180.

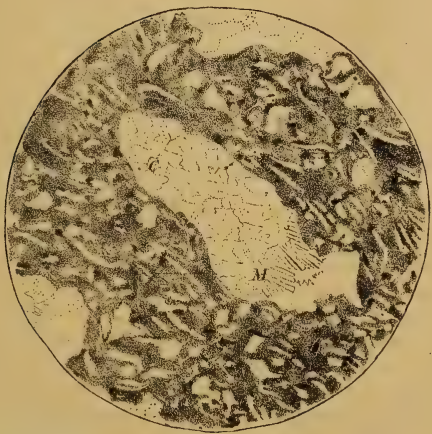


Fig. 3.
× 300.

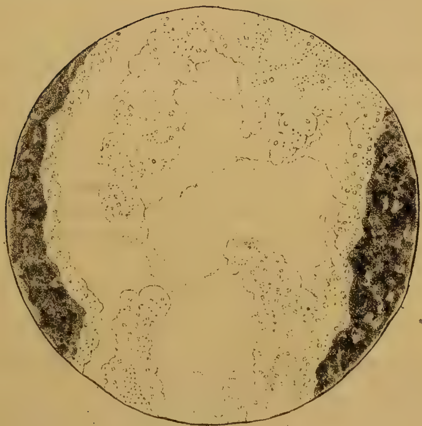


Fig. 2.
× 600.

ZEOLITES FORMED IN ROMAN BRICKWORK.

EXPLANATION OF PLATE IV.

Fig. 1. Opal with hyalite in globules forming numerous veinlets in brick. Enlarged 180 diameters. (White parts, opal; light dotted parts, hyalite; dark parts, brick.)

Fig. 2. The central portion of the principal vein in fig. 1. Enlarged 600 diameters.

Fig. 3. Chabasite and crystallized mesotype in a geode of the brick. (The magnesian mica of the brick is shown by the dark streaks. C, chabasite; M, mesotype.)

8. *On* Sand-worn Stones *from* New Zealand.

By J. D. Enys, Esq., F.G.S. (Read April 11, 1877.)

Before describing the Eolian or wind-worn stones, specimens of which are exhibited, I will give a short description of the locality from which they come. On the western side of the entrance to the Harbour of Wellington (situated on Cook's Straits, at the southern end of the North Island of New Zealand) is a peninsula attached to the mainland by an isthmus which has only a slight rise above the sea. This peninsula runs parallel to the mainland for two or three miles; and the connecting isthmus is about a mile across, dividing this space unevenly into two bays, which are known as Evans Bay and Lyells Bay.

On each side of the isthmus is a line of low sand hills; and between them is situated a flat piece of sand which is mixed with sufficient clay to form a hard bottom. On this rest the stones which are the subject of this paper.

Fig. 1.—*Sand-worn Stone showing an early stage of Eolian action.* (Half natural size.)

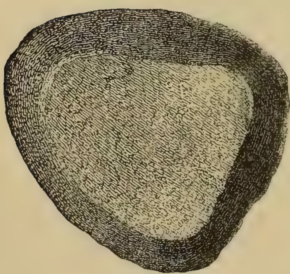
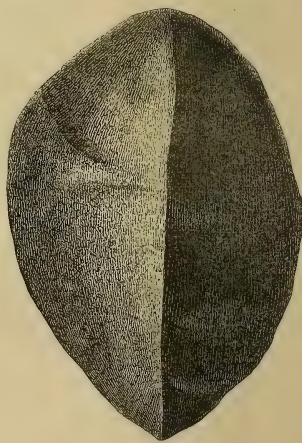


Fig. 2.—*Sand-worn Stone showing completed Eolian action.* (Half natural size.)



From the ground on both sides of these bays being of considerable height and lying north-west and south-east, the prevailing winds, which blow from the same directions with great force, drive a cloud of siliceous sand from one set of sand dunes to the other. This sand, on a windy day, forms a dense mass reaching to about the knees of any one walking over the ground. The result of this is the gradual wearing away of the stones on this flat ground. Originally of the ordinary shape of broken stone, they begin by showing sloping sides, as in fig. 1; and as the process goes on, the two sides gradually come together, and finally assume the shape of a triangle, as in fig. 2, with even angles and slightly convex sides, with rounded edges at the base.

Should the long axis of the stone lie in the line of the prevailing wind, the two sides of the stone are worn away to an even angle (fig. 2); but should the longer axis be slightly inclined to, or against the prevailing winds, I find that one side is much more quickly worn away than the other; and the stone then presents a triangular section with the one side longer than the other.

Amongst these stones I have found some with veins running through them of a harder material; and the result has been that the Eolian action has proceeded unevenly, leaving these veins standing above the softer matrix, but rounded like the veins in a man's hand (see the left side of fig. 2); indeed, when the veins were parallel to the base of the stone, the Eolian action has even undercut these veins.

A short time since, Mr. Stow, of Wellington, exhibited to the Wellington Philosophical Institute pieces of drift-pumice cut in a similar manner; these I had the pleasure of seeing at the time. These specimens came from the mouth of the river Waikat.

Many of the stones were brought to the neighbourhood by the natives to use in their cooking-places. These stones they first heat and then pour water on, which causes them to fracture in a conchoidal manner. These fragments I have seen in all states of manufacture by Eolian action.

These interesting stones were first noticed in 1869 by Mr. Hackworth; and a paper on them was read by Mr. W. T. Travers before the Wellington Society, Feb. 9th, 1869, which has been published in vol. ii. p. 246 of the 'Transactions of the New-Zealand Institute,' together with a plate.

Indeed it is only acting on the advice of friends to whom I have shown these specimens, that I have ventured to bring this paper before the Geological Society, that this curious instance of Eolian action may obtain a wider circulation than it has at present in the 'Transactions of the New-Zealand Institute.' The earlier numbers of that valuable work are, indeed, difficult to obtain.

Discussion.

Prof. Ramsay agreed with the author in his explanation of the mode of shaping of the stones. He remarked that in England there are numerous examples of Eolian action, which also occur in Egypt on a very large scale, level strata being in the latter country marked with grooves deeply ploughed by blown sand. As an English example he instanced the singular crags on the top of Kinder Scout. This forms part of a great tableland in Lower Carboniferous rocks; and upon it are club-shaped and mushroom-like pillars of sandstone, the formation of which has often been ascribed, wrongly in Prof.

Ramsay's opinion, to marine denudation. He stated that in the neighbourhood of these curious crags there is plenty of loose sand; and this having been blown with great force against the bases of the pillars, has cut them away into their present fantastic forms.

Mr. John Evans referred to various examples of stones polished by blown sand occurring in this country.

Prof. Boyd Dawkins remarked that if we wanted evidence of the erosive power of blown sand we had only to consider the effects of the sand-blast now so commonly used for the purpose of etching designs upon glass. He also cited examples in the African deserts of stones polished by the natural sand-blast. He stated, however, that he did not agree with Prof. Ramsay with respect to the origin of the crags on Kinder Scout, which, he remarked, is a wet locality, whilst, in order that it may cut in the manner suggested, the sand must be dry. The shaping of these peculiar crags was, in his opinion, due to the unequal weathering of rocks consisting of sandstones of unequal toughness.

9. *On the* Superficial Geology *of* British Columbia.

By George Mercer Dawson, Esq., D.Sc., F.G.S., Assoc. R.S.M., Assistant Director of the Geological Survey of Canada. (Read June 20, 1877.)

[Plate V.]

Contents.

The following notes give, in a summarized form, the chief observed facts of the Glacial period in British Columbia, obtained during the season's work in that province on the Geological Survey of Canada. They are offered as an extension to the Pacific coast of the observations carried in a former paper* to the Rocky Mountains.

1. Outline of Physical Geography.

For the purposes of this paper the eastern boundary of British Columbia may be regarded as coinciding with the Rocky-Mountain range, from which the province stretches westward to the Pacific, including Vancouver and the Queen-Charlotte Islands. Southward, the 49th parallel separates it from Washington Territory and parts of Idaho and Montana. To the north the Province-line is drawn on the 60th parallel. The area of British Columbia is roughly computed at 330,000 square miles, its exteme length, from corner to corner, being about 900 miles (see Map, Pl. V.).

The Rocky Mountains, many peaks in which surpass 9000 feet, are defined to the south-east by a remarkably deep and straight valley, in which are considerable portions of the courses of several of the largest rivers of the country. South-westward, beyond this great valley, is a second and broader mountain region, called by various names in different parts of its length, but which may be generally named the Selkirk or Gold range. Many of the summits of these mountains are scarcely less in altitude than those of the Rocky Mountains; and in many places they appear to be broad and plateau-like,

* Quart. Journ. Geol. Soc., Nov. 1875, vol. xxxi. p. 603.

with comparatively narrow intervening valleys. Nearly parallel to these two great ranges is the Coast or Cascade range, in which the average altitude of the higher peaks is between 6000 and 7000 feet, while some exceed 9000 feet. A fourth range may be traced, in a partly submerged condition, in the mountains of Vancouver and the Queen-Charlotte Islands. Between the Coast range and the Selkirk or Gold range lies the great interior plateau of British Columbia, with an average width of 100 miles, and a mean elevation of about 3500 feet. Its height, on the whole, increases to the south, while northward it falls gradually towards the cluster of great lakes, and the low country of the Peace-River valley. This plateau region has over a great part of its area been covered by wide-spread flows of basalt and other igneous rocks, in the later Tertiary period. It is now dissected by deep and trough-like river-valleys, into most of which water standing at 3000 feet above the present sea-level would penetrate, dividing its surface into a number of islands. In some places the plateau is pretty level and uniform; but usually it is only when broadly viewed that its character is apparent. The best published maps of British Columbia but imperfectly indicate even its grander physical features; but I believe, from information received, that the north-western end of the plateau is blocked by high mountainous country, formed by a coalescence of the three great ranges in latitude 55° 30′*. Nearly coincident with the 49th parallel is a second transverse mountainous zone, formed in a similar way, which may be considered as bounding the plateau to the south, though traversed by several great river-valleys, of which that of the Okanagan, in longitude 119° 30′, is the deepest.

No modern glaciers have been seen in the Rocky Mountains, near the 49th parallel, though much snow lies among the higher peaks, and northward, about the sources of the Saskatchewan, true glaciers are found. It is probable that some glaciers may also exist in parts of the Selkirk range. In the Coast range glaciers abound from the 49th parallel north-westward. To the south they are summit-glaciers, but northward, about latitude 51°, fill long valleys, and still further north are reported as coming down nearly to the sea-level in some places.

Three main structure-directions serve to account for the greater part of the depressions of the surface now occupied by rivers, lakes, and the fjords of the coast:—1, a north-westerly and south-easterly series of hollows, dependent on the general direction of folding of the rocks of the country; 2, a north and south, or meridional series, due, where I have had the opportunity of examining it, to systems of parallel cracking; 3, an east and west, or transverse series, occupied by many lakes and rivers, but the cause of which has not yet been determined. There are also traces, indicated by valleys in some parts of the map, of structure transverse to the main direction of folding. It is, of course, not intended to affirm that the causes mentioned produced these features directly, but merely that certain structural lines of weakness

* Called the Peak Mountains on old maps.

thus indicated were those on which eroding agencies afterwards shaped the country.

The arrangement of the lakes in British Columbia, and their long river-like forms, are very remarkable, suggesting at least the action of glacier ice, which, though it may possibly have formed rock-basins in some places, has generally, I believe, been instrumental in causing lakes by the arrangement of the drift-material in preexisting hollows. To the mode of formation of lakes in British Columbia I hope, however, on a future occasion to return, when more information may have been collected.

The fjords and passages of the coast, while quite analogous to those of Scotland, Norway, and Greenland, probably surpass those of any part of the world (unless it be the last-named country) in dimensions and complexity. They also appear to differ from those of Scotland and Norway in their narrower and more parallel-sided forms, and in the height of the walls which bound them. They are, no doubt, the valleys of rivers worn out when the coast stood at a greater elevation, and are all continued inland by deep gorges, in which streams still flow. The upper end of each inlet usually shows a small area of low swampy land, formed of material brought down by the river. It is continued seaward by a shallow flat for a short distance, and then dips steeply down, like the front of a terrace, into deep water. The arrangement of the material shows that the waters of the sea have long maintained nearly their present level. In following the inlets down they are found to be very deep, often as much as 150 fathoms, and sometimes over 200, though in most cases they are marked on the charts as 50 or 100 fathoms and no bottom. On arriving at the mouth of the fjord the water shoals—just as described in Scotland by Mr. Geikie. This I believe to be caused by the banking-up of sediment by the tidal currents, which run with great fury up and down the coast, but flow with decreased power into the sheltered fjords. There may be instances of true rock-basins; but the exact evidence required to put this question beyond doubt has not been obtained. In view of the deep and narrow chasms or cañons, in which many of the western rivers now run, and the difficulty, even if the whole outlet of a fjord is seen to be over rock, of proving the non-existence of drift-blocked channels in other directions, it is well to be cautious in the assumption of deep rock-basins when other causes quite competent to the explanation of the facts are at hand.

An elevation of the coast of British Columbia to a height of 150 feet above its present level, would now convert the inlets of the western part of Vancouver Island into a number of deep lakes, lying among the mountains, with their lower ends stretching out on a level, as a gently sloping plain of detrital material, over which their rivers would seek the ocean. The analogy of this state of affairs to that now obtaining with the strings of lakes following the slopes of some of the mountain-chains of the interior, will be evident from a glance at the map.

The highest mountain at Vancouver Island (Victoria Peak) attains an elevation of 7484 feet, while there is a considerable mountainous area in the centre of the island, which surpasses 2000 feet in average altitude.

2. Vancouver Island and the Coast.

a. Glaciation of Rock-surfaces.

The glaciation of the rocks in the vicinity of Victoria, Vancouver Island, is so well marked, and presents itself so immediately to any one arriving in the locality, that it has been mentioned by most writers on the country, and has been made the subject of remark by several geologists*. The rocks protruding from the soil, and projecting along the shores, are generally compact, coarser or fine-grained diorites and felsites, bedded or intrusive, which, while offering great resistance to abrasion, are well suited to preserve forms impressed on them. The direction of the ice-markings here has been variously given—a circumstance arising, I believe, chiefly from a want of attention to the magnetic variation, and the isolated character of the observations made. I am now, however, in a position to state, as the result of several hundred observations of the course of the striation, that but one general direction of movement is indicated in the whole south-eastern peninsula of Vancouver Island, the average bearing of which is about S. 11° W.†, and from which, except under certain special local circumstances mentioned below, there is seldom a departure of more than a few degrees on either side. At Sooke River, fifteen miles west of Victoria, the only distinct grooves seen have a course S. 18° W., which agrees closely with the above average direction, but is also parallel with that of the hills bounding the river valley. Grooving and striation are equally apparent at all elevations in the neighbourhood of Victoria, from low-water mark upward. The summit of Mount Douglas, or Cedar Hill, a rocky eminence 696 feet high, is quite distinctly glaciated, the direction being, as nearly as can be ascertained, due south. On looking northward from this hill on the wide expanse of the Strait of Georgia, no higher land appears for about fifteen miles, and then only as summits on scattered islands. Suitable localities for observation at greater altitudes are wanting in the vicinity; or ice-work could no doubt be traced to a yet higher level.

Rocks which, from their prominence, have been exposed to the full force of the ice, are generally grooved and fluted in the most remarkable manner (fig. 1), have been worn into boat-bottomed shapes, marked with parallel hollows often a foot or more in depth

* The glaciation of the southern part of Vancouver Island has been referred to by the following gentlemen:—H. Bauerman, "On the Geology of the South-eastern part of Vancouver Island," Quart. Journ. Geol. Soc. vol. xvi. p. 198. C. Forbes, M.D., 'Prize Essay on Vancouver Island,' 1862. R. Brown. "On Supposed absence of Drift on the Pacific Slope," Am. Journ. Sci. and Arts, 1870. George Gibbs, "On Physical Geography of the North-western Boundary of the United States," Journ. Am. Geog. Soc. 1874. A. R. C. Selwyn, "Report of Progress, Geol. Survey of Canada," 1871–72, p. 52.

† This and other bearings given are with reference to the true meridian.

and width, and show in all respects traces of having been subjected to the action of a great glacier. Where rocky hills are remarkably abrupt, their northern slopes only have received the full force of the

Fig. 1.—*Ice-grooved Rocks at Finlayson Point, Victoria, Vancouver Island.*

ice, which, borne up to some extent by their summits, has marked the southern slopes slightly and irregularly. A comparatively slight decrease in steepness of descent has, however, been sufficient in other cases, to enable the ice-mass to follow the contour of the rock, impressing the southern slopes with grooving almost as well marked as that of the northern. This is generally the case with the rocks forming the southern shore of the peninsula, where the furrows may be traced running regularly down beneath the sea. Here there is evidence of great lateral as well as downward pressure, vertical and nearly vertical surfaces being frequently as well polished as horizontal ones. Instances where rocks have actually been fluted and undercut at the sides are not uncommon (fig. 2). Another circumstance noticed in many places, dependent, no doubt, on combined vertical and great lateral pressure, and consequent "plasticity" of the ice, is the manner in which it has been made to fit to the rock-surfaces. Where a sudden drop of a few feet occurs to the south, a detached tongue of ice has moved obliquely beneath the general sheet on the lower side

Fig. 2.—*Sections transverse to Direction of Glaciation of Rocks undercut and fluted.* (Scale 5 feet to 1 inch.)

a. Coast-section between Victoria and Esquimalt.
b. West of Ogden Point, Victoria.
c. Esquimalt, face of cliff, 40 feet above sea-level.

[These and the following figures are facsimiles of the author's drawings.]

of the step, for some distance, till again carried onwards by the main flow. In one case, at Finlayson Point, divergence from the chief direction amounts to forty degrees. This point is on the west side of a large bay, continued northward by low ground, which must have formed the channel for a great mass of ice. The oblique grooves are so well worn as to be quite semicircular in the outline of their transverse sections. Here is also noticeable a very general tendency to slight divergence of furrows at the northern ends of rock-masses, and convergence round points to the south. In a few cases well-worn furrows showing this convergence are seen to be crossed at a small angle by comparatively light scratches, showing a "falling-off" of a few degrees from the normal course, due to the motion of the last portion of the retreating edge of the ice-mass, when, though forward movement still continued, lateral pressure had almost ceased. Selective erosion is a well-marked feature; and quartz sand being the hardest cutting-material available to the ice, portions of rock containing quartz in their composition show great powers of endurance compared with those consisting of felspar and hornblende only, though the latter may be quite as compact. Instances where quartzose intrusions protect long southward-pointing ribs or pencils of diorite are not rare.

There appears to be no escape from the conclusion that a glacier swept over the whole south-eastern peninsula of Vancouver Island at some time during the Glacial period; and on consideration of the physical features of the country it becomes apparent that the entire Strait of Georgia between the island and the mainland must have been filled with a great glacier, with a width, in some places, of over fifty miles, and a thickness near Victoria of *at least* considerably over 600 feet. With all this, however, there has been very little general wearing-down of the rock-surface of the country; all its main features, and, in many cases, even the most minute, are clearly of preglacial origin. The valleys generally follow bands of limestone and softer schistose and shaly beds, and run as often transverse to, as parallel with, the direction of glaciation; and besides the general forms of the smaller hills, little rocky knolls and projecting points of rock, while worn and rounded to the north, preserve rough unpolished southern faces. This feature is more marked than I have elsewhere observed, and would seem to indicate, even allowing that glaciers do not very rapidly abrade solid rocks, that the ice did not long rasp over this portion of the country, and possibly that it never extended much beyond this point.

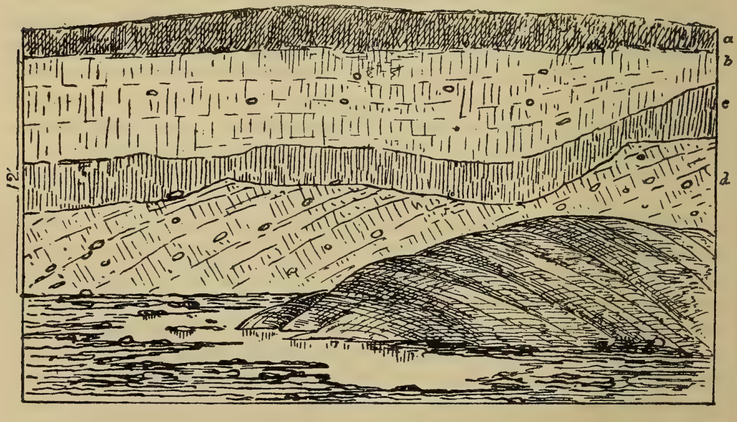
Mr. George Gibbs mentions the occurrence of glacial grooving running from north-east to south-west, on San-Juan Island, in the southern part of the Strait of Georgia, which would appear to show that the glacier must have pushed southwards towards the low country of Puget Sound, while a part may also have discharged westward into or through Fuca's Strait. Glacial striation is also reported on the mainland shore of the southern part of the Strait of Georgia.

b. Superficial Deposits.

The detrital deposits overlying these glaciated rocks are of a comparatively simple character. In the immediate neighbourhood of Victoria, near the sea-level, a material which I believe to represent *moraine profonde* occurs in a few localities, as a hard mass of sandy clay and stones, wedged into crevices in the rock, or protected by its overhanging ledges. Further inland, in the valleys of the Goldstream, Leech, and Sooke rivers, and small brooks tributary to them, a very similar material forms the greater part of the drift, and rests on rock-surfaces which, though generally smoothed, have only been observed to show direction of movement in the single locality already mentioned. Those valleys are deep, V-shaped in cross section, generally surrounded by rocky hills, and often transverse to the course of the ice; and they must have formed receptacles which, in course of time, were more or less completely filled with bottom-moraine, the remnants of which I believe the material above mentioned to represent, though possibly in some cases with the addition of pre-glacial river-gravels and alluvium. It is a very hard greyish-yellow sandy clay, crowded with subangular stones of varied origin, but generally quite small.

The ordinary deposits of the low south-eastern peninsula differ from these in being less consolidated and finer, and frequently show evident signs of stratification. The material most largely represented may be described as a hard, yellowish or pale yellowish-grey sandy clay, often having weather-stained cracks traversing it in all directions. This is frequently quite massive, and contains scattered stones and boulders, which are generally more or less rounded, and comparatively seldom show signs of glaciation, but occasionally do so very distinctly. In other places the deposit is more sandy and gravelly, and the bedding, which is often inclined, quite distinct. A very fine blue clay, which rests immediately, or with the intervention of a thin layer of gravel, on the rock-surface in sheltered hollows, is only a finer form of the same deposit, it being impossible to draw any line between this and the other classes of material. The deposits are occasionally very irregular, as though they had been stirred up by the grounding of floating ice, or some such cause; while false-bedding and appearance of water-disturbance are more frequent on points and the localities which must have been most exposed (fig. 3).

Fig. 3.—*Deposits overlying Glaciated Rocks, Victoria, Vancouver Island.*



a. Soil. *c.* Hard bluish clay, rusty cracks,
b. Yellowish-grey sandy clay. *d.* Sand and gravelly clay.

The drift-deposits frequently form cliffs or steep banks 30 or 40 feet in height, along the shore. Large boulders are found throughout, but are most abundant towards the top of the deposit, the clayey portion of which generally terminates rather abruptly above, and is often surmounted by a few feet of sand, gravel, and boulders much coarser than the rest, and probably, in part at least, due to rearrangement of the lower material along a coast-line during emergence. The mounds forming Beacon Hill, and those heaped on the north-east side of Spring Ridge behind the town of Victoria, are probably thicker masses of this surface-layer, though it is possible that portions of these, and similar mounds elsewhere, may represent remnants of moraines, terminal or lateral, left at different stages in the retreat of the glacier. They resemble much more closely, however, the deposits of stranding ice, considerably modified by currents. The materials in sections at Spring Ridge are coarse sands and gravels, with many boulders of all sizes. The largest boulders are nearest the surface, with their interstices filled with finer material, which also often forms the superficial layer of the deposit, as though, submergence still continuing, the supply of ice capable of transporting large blocks had failed.

Extensive banks of coarse sand and gravel have accumulated on the southern or lee side of Mount Douglas, before referred to, giving it a crag-and-tail form. At the head of Cadbury Bay, about 100 feet above the sea-level, a road-side cutting shows stratified false-bedded sands and gravels, the inclination of the beds, which is very regular, indicating north and south currents like those of the tides still running in the Strait of Georgia, the southward or ebb current being the stronger, and having most frequently left traces of its action. The boulders near Victoria are very frequently of diorites and granitic rocks, derived probably from the Cascade Mountains of the mainland to the north and east. Large masses of the Cretaceous coal-bearing rocks, and especially of the conglomerates, of Nanaimo are also not unfrequently met with. The boulders, as well as the finer materials, are occasionally found forming accumulations behind rocky ridges. The largest erratic mass observed lies near Cedar-Hill church, and measures 17 feet long, 9 feet 11 inches wide, and 7 feet in thickness, though partially imbedded in the soil.

Mr. Bauerman mentions the occurrence of casts of *Cardium* and *Mya* in these deposits, an observation which for a long time I was unable to confirm; but eventually several localities were discovered where molluscous remains are tolerably abundant. These shells were not noted in the lowest portions of the drift. They are generally contained in hard fawn-coloured sandy clay, almost without stratification, and are frequently quite decayed and crumbling, though found with the valves united in the position of life. Granitic fragments included in the clay are also very frequently more or less decomposed, and sometimes completely rotten, showing that carbonated surface-waters here long acted on the mass since its elevation. This action may probably account for the comparative scarcity of the shells, while its continuance for a period somewhat more prolonged would without doubt have resulted in their total removal. The beds so affected are at a height of only a few feet above the sea; and this, coupled with their resemblance in texture to many inland drift-deposits, suggests one means of accounting for the apparently complete absence of marine remains over areas which on other evidence appear undoubtedly to have been at one time submarine, but which from their elevation must have been much longer exposed to the percolation of surface-waters.

The following species have been recognized among the fossils hitherto found :—

Cardium islandicum.
Leda fossa.
Saxicava rugosa.
Natica clausa (probably).
Balanus crenatus (probably).

In localities where the upper sandy and gravelly layer of the drift is not developed, the change from deep water to littoral conditions appears to be marked by the rather sudden introduction of carbonaceous matter, changing the clayey deposits from their usual pale tints to dark brown. In some places marine shells, and especially the *Cardium* above named, appear sparsely in the highest layers of the pale clays ; while in other localities, near the present shore-line, the lowest layers of the shell-heaps, and burnt stones used by the Indians in cooking, coincide with those of the brown earth, showing apparently that the last movement of elevation by which the land attained about its present level was rather sudden, and that habitation by a race resembling the present natives followed closely on the termination of the glacial conditions.

The general appearance of the deposits of this part of Vancouver Island, resting, as they do, on planed and polished rocks perfect in every detail and necessitating glacier-action for their explanation, and yet consisting of water-bedded and often current-driven materials mingled in places with sea-shells, leads to the belief that they were formed along the retreating foot of a glacier which had extended some distance beyond the margin of the land. The withdrawal of the ice may have been caused or accompanied by subsidence; and some species of shells must have followed its front pretty closely in its retreat. The somewhat irregularly terraced form of the deposit is probably due to action during emergence ; and the general tendency of many facts is to show that a slight sinking of the coast is at present in progress or has lately occurred.

Occasional artificial sections at New Westminster, at the mouth of the Fraser river, on the opposite side of the Strait of Georgia, show deposits quite similar in general features to those seen near Victoria ; but no molluscous remains have been found. These beds pass under the modern flat and wide delta of the river, which extends many miles seaward. Some of the higher parts of the irregular terraces about Victoria, may be correlated in a rough way with the edge of the sloping ground on which New Westminster is built ; and several islands in the southern part of the strait show cliffs of similar materials and about the same height. St.-James Island may be specially mentioned, its white cliffs, probably eighty feet high, forming a prominent landmark. Vancouver Island has probably been united at one time to these smaller islands and the mainland by a floor of deposits at about this level, though there is nothing to show that it has ever formed an actual land connexion.

c. Observations northward in the Strait of Georgia and at Bute Inlet.

One hundred miles northward in the Strait, deposits similar to those last described form scarped banks along the shores of Savory, Hernando, Mary, the southern portion of Valdez Island and the low eastern shore of Vancouver. Fragments of a terrace, estimated from a distance to be from sixty to eighty feet in height, are seen on the inner side of Stuart Island in the entrance of Bute Inlet, and at one other place some miles up the inlet on the west side. No higher terraces or accumulations of detrital matter were seen on this part of the coast; but Mr. Richardson mentions terrace-deposits at heights between 100 and 200 feet in Kitemat Inlet, further north. The remarkable rarity of terraces, however, and absence of drift-material on the western slope of the coast-range, are among its most striking features, contrasting strongly with the condition of its inland margin.

My opportunities for examining the remarkable fjords by which the coast of the mainland is indented have been limited, the only one ascended to the head being Bute Inlet. This chasm, forty miles in length, and running into the centre of the coast-range, is surrounded by mountains which, in some places, rise from its borders in cliffs and rocky slopes to a height of from 6000 to 8000 feet. It must have been one of the many tributaries of the great glacier of the Strait of Georgia, and accordingly shows evidence of powerful ice-action. The islands about its mouth are *roches moutonnées*, polished and ground wherever the original surface has been preserved. In Sutil Passage, near its entrance, grooving appears to run about S. 30° W. A precipitous mountain on Valdez Island, opposite Stuart Island, and directly blocking the mouth of the inlet, though 3013 feet high, has been smoothed to its summit on the north side, while rough towards the south. The mountain-side above Arran Passage, shows smooth and glistening surfaces at least 2000 feet up its face; and in general all the mountains surrounding the fjord present the appearance of having been heavily glaciated, with the exception of from 1000 to 2000 feet of the highest peaks. The high summits are rugged and pointed, and may either never have been covered by glacier-ice, or owe their different appearance to more prolonged weathering since its disappearance. In some places parallel flutings high up the mountain-sides evidence the action of the glacier; while in others it is only attested by the general form of the slopes, or detected under certain effects of light and shade. The mountain-sides are wonderfully bare, and even when wooded have a very scanty covering of soil; so that after the natural forest has been destroyed by fire the naked rock everywhere appears. At the mouth of the Howathco river discharging into the head of Bute Inlet, striation shows a direction of movement S. 22° E.; but in every case the motion appears to have been directly down the valley, and to have conformed to its changes in course. Glacier-ice may still be seen shining bluely from some of the higher valleys at the head of the inlet, and further up the Howathco river there are many glaciers in lateral valleys, some of which descend almost to the river-level.

Mr. James Richardson, who has had an opportunity of examining many of the inlets north of Vancouver Island, writes as follows* —"Throughout the whole of the inlets and channels which were examined, wherever the surface of the rock is exposed, the ice-grooving and scratching is very conspicuous, from mere scratches to channels often several feet in width, and from a few inches to as much as two or three feet in depth. Often they can be distinctly seen with the naked eye, from the surface of the water to upwards of 3000 feet above it on the sides of the mountains. They run in more or less parallel lines, and are not always horizontal, but deviate slightly up or down."

3. Interior of British Columbia.

The region lying between the Cascade or Coast Mountains on the west, and the Selkirk or Gold range and Rocky Mountains to the east, though it may be be regarded in a general way as a great plateau sloping gradually to the north, from its broken and diversified character offers a problem with many additional elements of complication. The phenomena may be divided as before, under the heads of rock-marking or striation, and overlying detrital deposits. The striation, however, admits of subdivision into many different systems; and the superficial deposits may be classed as unmodified and modified drift and moraines, between which lines can be drawn in a manner which, though even here not always absolutely definite, could not be attempted with the drift covering the southern part of Vancouver Island.

a. Striation and Rock-polishing.

In several cases I have observed grooving at such heights and with such bearings as to preclude the possibility of its being attributed to glaciers moving from any of the present mountain-systems, and seeming to require for its explanation ice-action on a very much greater scale. As few localities offer, however, where traces of this character can be observed under quite unequivocal circumstances, it may be proper, in view of their interest, to treat of the more important in some detail.

Tsa-whuz Mountain (lat. 53° 40′), on the direct trail from Blackwater Bridge to Fort George, is an isolated basaltic outlyer, rising about 800 feet above the higher parts of the surrounding hilly plateau, about midway between the valleys of the Fraser and Chillacco rivers, which lie east and west of it. Its approximate

* Report of Progress Geol. Survey of Can. 1874–75, p. 8.

elevation above the sea is 3240 feet; and standing on the summit, one commands a very extensive view in all directions. Westward, at a distance of about fifteen miles, across the deep Fraser valley, hills surpassing this in altitude are seen. Southward no part of the surface of the country is so high till beyond the valley of the Blackwater river, at a distance of over thirty miles. Westward and south-westward, with the exception of one hill of about equal height, the plateau stretches for from fifteen to twenty miles; while through more than a quadrant of arc to the north, the whole country appears to slope gradually away from the foot of Tsa-whuz, towards the low region about McLeod Lake and the Parsnip river, and forms a level sea-like horizon. No high mountains appear in any bearing. The rocks of the summit of Tsa-whuz are for the most part roughened by the weather; but in several places indistinct striation is seen; and in one spot, within a few feet of the highest point, a slightly overhanging surface of basalt was observed to be distinctly shaped and polished by ice, the direction indicated being a few degrees west of south. The surface of the northern ridge of the mountain shows miniature rock-basins, with their longer axes parallel to the same direction, and some of them holding small pools. The ridges which diversify the surface of the plateau below are seen to conform very generally to north-and-south bearings; and this is especially observable immediately to the south of Tsa-whuz, where a succession of small ridges are closely packed together, with their longer axes running S. 25° W. Some of these hillocks probably owe their form to that of the underlying rock, while others are no doubt composed of gravel; and the general form of these and of Tsa-whuz is as though the glaciating agent had moved from north to south.

Traces of glaciation were also noticed in several places at high levels on the basaltic plateau in the vicinity of the Fraser valley, in positions not allowing their being referred to local action. In two cases very distinct grooving was observed. In one of these localities, about twenty miles north of the Chilcotin river, and several miles distant from the trough of the Fraser, the direction is nearly true north and south, the approximate elevation being 3350 feet. In a second instance, also on the summit of the plateau, on the northern brink of the Chilcotin valley (lat. 52°), at an elevation of about 3650 feet, with a direction of S. 23° W., or N. 23° E., being transverse to the present great gorge of the Chilcotin river, the surface of the narrow basaltic plateau forming the summit between the south-western tributaries of the Nechacco and some of the north-western branches of the Blackwater, at an elevation of 3730 feet, is ice-smoothed, but the direction of motion is undeterminable.

On the summit of a hill which we may call Sinter Knoll, rising about 250 feet above the general level of the country, or 3550 feet above the sea, north of Gatcho Lake, near the south-eastern sources of the Nechacco river, glaciation occurs with a bearing about S. 8° E. The rock of the hill is a remarkably brecciated siliceous material—hard, but much jointed. The striation was only found on one spot, protected by a foreign boulder, which had to be overturned before it could be observed. The glaciated surface is considerably inclined and beautifully polished, with faint scratches crossing each other at small angles. The abrupt southern face, and the more gentle northward slope of the hill, appear to show that the ice must have moved southward. From N. 30° E., round to N. 18° W.; and beyond, the highest country within many miles is a ridge with an elevation from 100 to 300 feet greater than that of the Sinter Knoll; and beyond this only low blue hills are seen at a distance estimated at from fifteen to twenty miles.

One of the most remarkable localities in which glaciation referable to this system was found, is a rocky hill south of the Salmon or Dean river, isolated from the higher parts of Tsi-tsutl Mountain, of which it forms an outlier, by a shallow valley about a mile wide. The altitude of this point is 3700 feet. Westward the view is across the lower broken country of the Tahyesco river to the snow-clad eastern parts of the Coast range at a distance of from twelve to fifteen miles. A line drawn south-westward would cross obliquely this wide valley for many miles before higher country would be reached. To the north, the lower region and minor elevations, mentioned in connexion with the last locality, are overlooked. The rocky surface of this hill has been smoothed and striated by ice moving S. 37° W., forced apparently somewhat out of its usual course by the flank of Tsi-tsutl Mountain, and passing between it and the Coast range.

Near Hatty Lake, nearly 1000 feet lower than the last locality, and sixteen miles north-east of it, in a narrow pass between cliffs of hard Mesozoic rocks, ice has left unmistakable traces of its passage south-westward, glaciating not only horizontal, but nearly vertical rock-surfaces. It has conformed in its direction to the tributary valley of Salmon river, in which it is seen, the valley being nearly parallel to the main direction of that of the Salmon river, which runs towards the Coast range, and through it to the sea.

Glaciation clearly referable to ice spreading from the Cascade or Coast Mountains, and other ranges, is met with in many places; and generally speaking, wherever circumstances admit of their observation, grooving and striation parallel to the main courses of the valleys, and depressions radiating from or passing through all the higher mountains, may be found. These facts, however, possessing only a local interest, need not be detailed here. Other features of local glaciation will be again referred to.

b. Superficial Deposits.

Preglacial Gravels.—It is quite probable that in many localities deposits of Preglacial date, but newer than the basalt-flows which appear to have closed the Miocene period, may occur, especially in deep and steep-sided valleys. A hasty examination of the Cariboo gold-mining district appears to show that while in some valleys, especially those facing northward (*e. g.* Mosquito Creek), Boulder-clay lies directly on the rock surface ; in others the rich gold-bearing gravels are quite distinct from and below this deposit. In Lightning Creek, the material filling the bottom of the old stream-course, often from 50 to 100 feet below the present brook, is a water-wasted gravel, with little clay and no cementing matter, but much compacted by pressure. This is richly auriferous, and has been followed by extensive mining-operations. Above it, in the valley-bottom and clothing the sides of the surrounding hills, is Boulder-clay, which yields little gold ; and on this again are recent modified deposits of gravel, over which the stream of to-day finds its course. These last are generally also more or less auriferous, forming "shallow diggings."

Unmodified Drift.—The whole interior of British Columbia, up to elevations of over 5000 feet, may be said to be more or less thickly mantled with unmodified or scarcely stratified deposits, which I shall refer to as *Boulder-clay*. Over considerable areas this material is concealed beneath later accumulations, which form terraces and low-level flats, in relation to present and former lake- and river-valleys. There is a remarkable uniformity about these Boulder-clays in every locality in which I have examined them. In many places they form low rolling and broken hills, between the river-troughs, above the level of the higher terraces. In this case they appear sometimes to be spread in a comparatively thin layer over a rocky substratum ; while in others they are of great depth, and, by the irregularity of their arrangement, themselves produce many of the minor features of the surface. They frequently show a tendency to form more or less well-defined high-level plateaux, and are spread almost universally over the elevated basaltic region of the interior, in most places so uniformly, notwithstanding minor irregularities, as to allow the underlying rock to be very seldom seen. The Boulder-clay is quite typically developed on the basaltic plateau crossed by the main waggon-road between Clinton and Bridge Creek. This plain, isolated by deep river-valleys, is traversed by the road for a distance of about thirty-five miles, and has an elevation of from 3900 to 4200 feet. The Boulder-clay may be described as consisting of a paste of hard clay, always more or less arenaceous, and generally with a very considerable proportion of fine sandy material, through which stones of all sizes are irregularly scattered. Its usual colour varies from light-brown to pale greyish-brown and fawn-colour, but in freshly exposed sections is sometimes bluish-grey. It very often, over extensive regions, forms the soil in which the trees are rooted, without the intervention of any modified material, and is frequently so arranged as to surround larger or smaller depressions which hold lakes and swamps. The greater part of the stones and boulders contained in the clay or scattered over its surface, are almost invariably rounded and waterworn, and sometimes very perfectly so ; yet a proportion showing distinct glacial striation, and some glaciated fragments worn flat on one or more sides, may always be found. The quantity of distinctly glaciated material varies much with locality, and, no doubt, depends in part on the nature of the rocks themselves. The pebbles and boulders very generally show a clear relation to the rocks of the country over which they lie, being composed in great part of these rocks, but mingled always with some proportion of foreign material. The surface of the basaltic plateau above described shows, for instance, not only basalt of varied texture in great abundance, but a considerable quantity of fragments from the Lower Cache Creek Series of the Geological-Survey Reports; some, pretty certainly derived from the Cascade Crystalline Series; and others, of which it is not always possible to trace the source, but which certainly do not occur on the plateau. Where those varieties of basalt which easily break on weathering into polygonal fragments occur, the overlying Boulder-clay is filled with them, so that in many places, after prolonged subaërial weathering, the surface appears to be absolutely composed of blocks of stone.

The general direction of movement of the travelled constituents of the Boulder-clay appears to have been southward, though the diversity of the rock formations, and our present ignorance of the details of their distribution, preclude to a great extent, the use of erratics in this inquiry.

Boulder-clay has been noted in the Cariboo country up to over 4500 feet, though the stony materials appear near this elevation to be becoming more angular. The state of the weather during my visit to the region prevented the examination of higher levels. Between Quesnel and Blackwater Bridge it forms an undulating plateau, of which many portions surpass 3000 feet, levelling up the irregularly hilly surface of the hard old rocks below. Between Blackwater Bridge and Fort George it appears at all heights up to over 3400 feet. Waterworn transported pebbles are found on the summit of Tsa-whuz Mountain, above mentioned, while on its northern slope a great collection of larger erratics appears. North of the Blackwater, in longitude 124° 30′, several broad ridges with elevations of from 4000 to 4300 feet are entirely covered with drift-material, with the addition of great numbers of boulders larger than are elsewhere seen. Two high hills passed over by the trail from Fraser to Stuart Lake, with elevations of 3792 and 4910 feet, are covered to the summit with Boulder-clay of the usual appearance, but holding more well-glaciated stones than usual, some of which have evidently been derived from the north. In the Chilcotin country similar deposits overlie the basaltic plateau at elevations above 3000 feet. These instances may serve to illustrate the distribution of the Boulder-clay without entering further into details or attempting to describe the numerous localities in which it has been examined.

In one place only have I found what I believe to be the upward limit of these deposits. This is on the northern slope of the Il-ga-chuz Mountain, at an elevation of 5270 feet, where it coincides with the highest known shore-line.

In the mixed character of the stones of the Boulder-clay and their very generally rounded and waterworn aspect, though enclosed in material with little or no stratification, the action of water-borne ice, whether iceberg, floe, or shore-ice, seems to be indicated.

Modified Drift.—As already mentioned, extensive areas of the boulder-clays are entirely concealed by newer overlying deposits. It may be almost stated as a rule that, in regions lying lower than 3000 feet, the superficial materials are entirely of this more recent date. These are often clearly traceable to ancient lakes, of which they yet define the outlines, but in other cases are due merely to the successive rearrangement of material by rivers slowly cutting down their valleys. The extent of surface below the above-mentioned limit in the southern part of British Columbia is comparatively small; and the more or less isolated later deposits present varying local characters. To the north, however, the general lower elevation of the country has allowed the formation of beds more wide-spread and important. I have examined the southern portion only of this lower area, the northern extension of which passes in a wide belt along the Parsnip and through the Peace river-depressions in the Rocky Mountains to the great Mackenzie river-basin*.

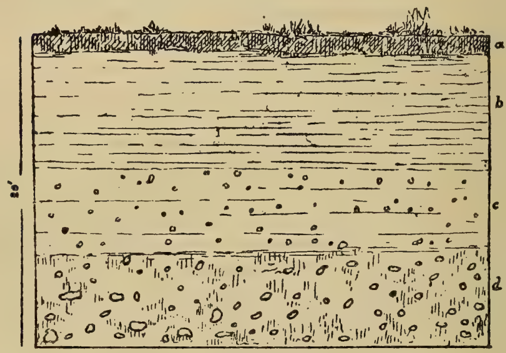
The best sections of the deposits of this northern area are found in the Lower Nechacco basin, between lat. 53° 30′ and 54° 10′, and long. 123° and 124° 40′. They reach a height of about 2400 feet at the edges of their basin, and where seen lowest (near Fort George) have an elevation of 1900 feet. Their known area is about 1000 square miles; but they may extend far northward. They seem to represent an interesting epoch of the Glacial period, and are composed of nearly white, greyish or pale chocolate-grey arenaceous clay, divided by distinct stratification-planes into layers an inch or two in thickness, and very uniform in this respect. When dry the material is hard, but not sufficiently homogeneous to break regardless of bedding-planes. Under the microscope it is seen to be made up of very fine angular quartzose particles, mingled with a little formless argillaceous material. It is usually calcareous, and is filled in many sections with calcareous nodules, generally lenticular, but often confluent, forming grotesque aggregations. These are especially abundant on the shore of Stuart Lake near Fort St. James, and in some of the Nechacco-River sections. I have called these deposits the *White Silts*.

The beds are sometimes seen to be disturbed, and even more or less contorted—an appearance which has, I think, often been produced by "slides" in the banks of the river of comparatively recent date. Contortion, however, sometimes seems to have been caused by the contemporaneous action of floating ice, the presence of which is proved by the occasional occurrence of large subangular boulders, which generally lie in groups, and are often as much as two feet in diameter. The portions of the formation holding many boulders seldom show distinct bedding, though composed of material similar to the rest, and not mixed with much gravel or beds of coarse detritus intermediate in character between the fine matrix and the erratics. In some cases the White Silts are found to have been deposited in gently inclined beds on preexisting sloping surfaces. They

* Selwyn, Report of Progress Geol. Surv. of Canada, 1875–76.

are occasionally seen on the Nechacco below Fraser Lake to rest on false-bedded sands and clayey gravels (which may here probably represent a part of the Boulder-clay), and were observed to overlie in one section a hard yellowish sandy clay with few stones. The White Silts are also found to rest directly on denuded Tertiary beds and other older rocks. In one section on the Lower Nechacco, their relation to well-marked Boulder-clay is very distinctly seen (fig. 4).

Fig. 4.—*Section on Lower Nechacco River.*



a. Soil. *b.* White Silt.
c. Hard, grey, sandy clay, with rounded and subangular stones, some glaciated.
d. Bluish sandy clay, with boulders and pebbles generally somewhat water-rounded, but nearly all glaciated more or less distinctly.

The lowest bed exposed here is a hard bluish arenaceous clay, with small boulders, and pebbles of all sizes, mostly more or less water-worn, but nearly all showing traces of glaciation. There is little or no appearance of stratification. This is separated by a distinct horizontal line from the next layer, which is paler in colour, harder, and somewhat more arenaceous, and charged with smaller pebbles less evidently glaciated. The stratification is obscure. A second sharp horizontal line separates this bed from the overlying White Silts—hard pale arenaceous clays of the usual character, which become disintegrated above to form the soil.

The thickness of the White Silts must be over 100 feet in some sections, and might very probably, if fully exposed, be found in many parts to exceed 200 feet. The deposit shows a close general resemblance to the thick argillo-arenaceous or loess-like material of the plains of the Red River in Manitoba; and very similar conditions may probably have led to the formation of these beds in the two localities. In both Manitoba and the Nechacco basin the material is generally calcareous, and in both places it forms a most fertile soil. In the Nechacco country it seems probable that the silts were laid down in the bottom of a great lake, at a time when all the present smaller basins were united, which may possibly have allowed the access of the sea to some extent. They have the appearance of being the deposit from water charged with fine glacier-mud, or flour of rock; while the presence of glaciated boulders proves either that some of the glaciers yet extended far enough from their sources to reach the waters of the lake, or that heavy coast-ice existed.

In approaching the mouth of the Nechacco, gravelly deposits of great thickness are found, forming exposures in some banks over 200 feet in height. The gravels alternate irregularly with sands; and the whole is quite frequently false-bedded on such a scale as to imply very strong current-action. The material of the gravels here too ceases to bear so close a relation to the country rock, becoming mixed with a considerable proportion of quartzite shingle, the origin of which will be referred to hereafter. These sandy and gravelly beds appear in the main to intervene between the Boulder-clay and the White Silts, but are most closely related to the latter. They may indicate the course of stronger currents coming from the north with much shingle-laden coast-ice, the upper part of the Nechacco basin being at this time a great sheltered bay in which the more typically developed White Silts were being formed. With the exception of the Fraser valley, which may have been filled with the earlier drift deposits, the lowest gap in the southern rim of the White-Silt basin is found near the southern sources of the Chilacco, at an elevation of 2660 feet; and here a wide belt of country shows coarse and fine superficial sandy deposits, with little gravel, forming low mounds and ridges, which evidently owe their forms to moderately powerful current-action, and may show the southern continuation of the current above indicated.

Shore-lines, Terraces and Benches.—The interior of British Columbia shows water-marks in different stages of preservation, from a height of 5270 feet down to the present sea-level. Some facts bearing on this division of the subject have already been given in connexion with other matters; it will be necessary here to give only a brief review of the more important features, mentioning a little more fully a few of the most remarkable. It is necessary, though sometimes difficult, to distinguish as far as possible between shore-lines of the sea or former great lakes, and terraces which are due to the gradual lowering by erosion of river-beds in their valleys, which bear a quite different significance.

The highest observed beach is that of which the elevation (5270 feet*) has already been given as probably the upward limit of the Boulder-clay; it was found on the northern slope of Il-ga-chuz Mountain. The undulating and more or less broken plateau stretching eastward from this mountain, with a general elevation of about 4500 feet, appears to owe the form of its surface in great part to the arrangement of drift upon it, and shows much foreign material. On

* This height may be regarded as fixed with some accuracy, the figures being the mean obtained from two barometric observations made on the terrace, and simultaneously at a neighbouring station, of which the elevation had been instrumentally fixed.

July 22nd we camped on the north-east slope of the mountain, in the valley of a little stream which, after running between high sloping banks for about a quarter of a mile, opens widely north-eastward, in which direction the whole surface at the same time slopes away. Here distinct though somewhat worn terrace-marks occur in the sides of the little valley; and in travelling a short distance westward along the mountain-side, there may be observed to spread quite beyond the valley of the brook, and form an extensive, nearly level or only gently undulating, flat on its northern slope. The material of the flat is evidently rolled and water-rounded, like beach-shingle, and, though in great part derived from the volcanic rocks or the mountain itself, has a considerable percentage of travelled stones, some of which are as much as a foot in diameter. At higher levels on the mountain-side this rounded material does not appear, and, as far as observed, no fragments not referable to the rocks of the mountain occur. Northward, with the possible exception of one peak forty miles off, no land equal in height to this terrace is in sight. The average elevation of the country is probably 2000 feet less. I have not had the opportunity of examining other parts of this mountain or the ranges east and west of it with care; but from a distance the south-east side of this one shows a well-marked line, separating the higher peaks from the low sloping base. This was noted and sketched as a marked feature before the existence of the shore-line above described was known (fig. 5). In height the two must nearly if not exactly agree; and it is more than probable that the different appearance of the lower and upper parts of the mountain is largely owing to the distribution of the drift upon it.

The general evidence of the submergence of the interior during the formation of the Boulder-clay to an extent of from 4000 to 5000 feet, depending on the composition and appearance of that deposit, has already been given. The tendency of the Boulder-clay to form elevated undulating plateaux, even when unsupported by the basaltic plateau and resting on an uneven surface, has also been referred to. When terraces occur in series upwards from river- or lake-valleys to the summit of the plateau, the highest generally consist not of water-washed sands and gravels, but of Boulder-clay, little or not at all modified—a circumstance seeming to prove the formation of the Boulder-clay to have been still in progress while the water passed through the first stages of its retreat. In ascending from the Blackwater, these Boulder-clay terraces appear at about 3150 feet.

The north-eastern or upper end of Tatlayoco Lake touches the plateau-country, while its south-western stretches into the Coast Mountains, through which its waters eventually pass to the sea. Its elevation is 2747 feet; and terraces quite well marked appear on its south-eastern side to a height estimated at 1500 feet above its waters, or 4250 feet above the sea. Fraser and François Lakes are bordered by terraces, the best-marked being estimated at 100 and 200 feet above the lakes respectively, which, allowing for their difference in height, no doubt represent the same water-line, the approximate elevation of which above the sea is 2350 feet. The hills

Fig. 5.—*Distant view of Il-ga-chuz Mountain from the South-east, showing probable upward limit of drift-deposits.*

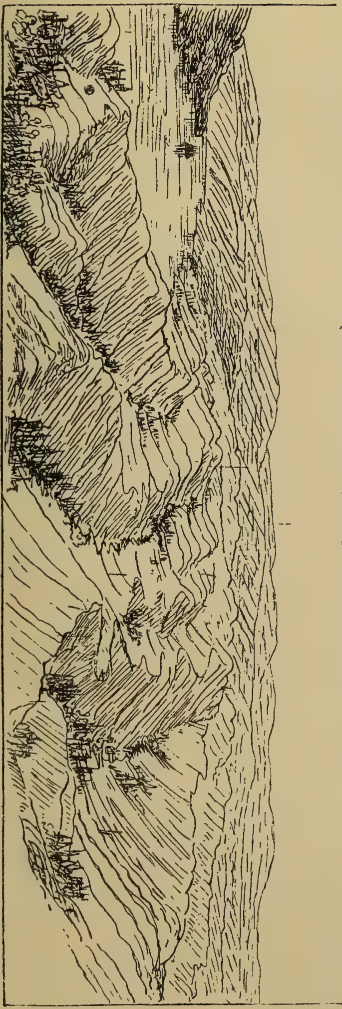


Fig. 6.—*Moraines on the Nechacco River near outlet of Na-tal-kuz Lake.*
(Lat. 53° 25′ N., long. 125° 10′ W.)

between Fraser and Stuart Lakes, already mentioned, show a succession of water-marks in some places to an elevation of at least 3800 feet. They stand in a low country as spurs or outliers in the basin of the White Silts. Mr. Smith, of the Canadian Pacific-Railway Survey, gives the general height of the highest well-marked beaches of the Fraser and its tributaries, which he has observed in different localities more than 150 miles apart, at from 2400 to 2500 feet. To this stage the Fraser and François Lake-terraces no doubt belong.

Some beaches, remarkable from the nature of the material composing them, occur on the direct trail to Fort George, between Tsa-whuz Mountain and that place. The aspect of the country from Tsa-whuz, and its general northern slope, have already been described. In gradually descending the slope, towards the basin of the White Silts, Boulder-clay, previously forming the surface, nearly disappears, and is replaced or covered by shingly deposits composed of well-rounded stones, which are for the most part very compact quartzites of various pale tints, almost precisely resembling the quartzite drift formerly described as occurring on the higher levels of the plains east of the Rocky Mountains*, and would appear probably to have been derived from the same series of rocks. The shingle beaches or mounds have no very uniform general direction, but form low gently-swelling undulations which bear forests of scrub-pine, separated by swampy hollows densely filled with black spruce. The shingle-beds may, I think, be pretty safely correlated with the thick gravelly deposits seen at a lower level near Fort George, and, if so, probably represent the margin of the White-Silt sea at one stage. Their approximate average elevation may be stated as 2100 feet. An interesting question occurs with regard to the origin of their materials. No rocks similar in character to their quartzites have been found in this part of British Columbia. It is probable that they have been far transported across the northern low country, or derived from exposures on the northern spurs of the Cariboo range.

The materials of the lower terraces of the river-valleys, though sometimes interesting, are more local in their character, and not significant in tracing the origin of the drift-deposits as a whole. The terraces in the bottoms of the valleys, and nearest the bed of the stream, usually show the coarsest gravels. The rivers being in almost all cases rapid streams, subject to great floods in the early summer, constant transport of material is still going on in their channels; and in consequence the river-gravels do not bear nearly so close a relation to the local formations as those higher up the slopes of the valleys and on the plateau. In passing in a canoe down those parts of the Fraser which are considered navigable, one is constantly struck by the peculiar sharp hissing noise caused by the grinding and onward movement of the gravel in the river-bottom. This may be heard in all the "riffles," or little rapids, even at low water, and evidences the extensive transport and consequent corrosion in pro-

* Quart. Journ. Geol. Soc. Nov. 1875, vol. xxxi. p. 616, and 'Geology and Resources of the 49th Parallel,' p. 231.

gress. As a result of this action in the Fraser, the quartzite drift developed in the vicinity of Fort George has been dragged down stream in great quantity, and can still, I believe, be recognized as an important constituent of the gravel banks to near tide-water.

The display of terraces or "benches" on the Fraser and Thompson rivers and some of their tributary streams is probably as imposing as can be seen anywhere. In some cases they may show merely stages in the descent of the rivers to their present levels through the wide-spread deposits of the Glacial period; but as many of them, and especially those of the higher levels, are seen to leave the immediate valleys of the rivers, attach themselves to the bases of the hills, and fringe at similar elevations all the ramifications of the streams into the plateau, it would seem that some at least must owe their origin to the general inundation of the country, and its subsequent gradual drainage. Such an overflow may have been the result of a general depression of the land, or of the stoppage of the southern outlets, more especially of the Fraser valley, and, for the higher terraces, those also of the streams running southward across the 49th parallel. Partial movements of upheaval and depression might also account for the damming-back of water in valleys previously formed; but of this no evidence has yet been found*.

In travelling up the Fraser valley through the Coast-range, one has the widest opening anywhere existing through these mountains at one's back; yet, step by step, the terraces can be followed from near the sea-level to the highest water-marks observed. At Yale, on the outer border of the range, 160 feet above the sea, are terraces with narrow treads, composed chiefly of angular débris, but forming well-marked horizontal lines on the mountain-slopes. One of these, barometrically measured by my friend Mr. A. Bowman, was found to have an elevation of 800 feet above Yale. The highest perfectly distinct line was estimated to reach 1500 feet. It may be open to question whether these benches may not be remnants of lateral moraines of an old great glacier which has filled the valley. They look, however, like shore-lines, caused by the accumulation and horizontal arrangement below the water-line of débris from the mountain-slopes.

Following the gorge or cañon of the river through the Coast-range, besides lower terraces from 100 to 200 feet above the stream, everywhere visible, occasional fragments of benches bearing a close resemblance to those at Yale, may be seen perched far up on the mountain-sides. About a mile above the Stoyoma river of the Admiralty Map (25 miles above Yale) some of these were estimated to be as much as 2000 feet above the water, or about 2450 feet above the sea. At Boston Bar terraces estimated at about the same height were seen. Near Lytton the Thompson river joins the Fraser, the valleys become wider and the terraces well-defined and broad. One, baro-

* Mr. Selwyn discusses some of these points in the Report of Progress Geol. Surv. of Canada, 1871-72 (p. 55). Sir Matthew Begbie has also published some account of the terraces of the Fraser; but I have not been able to refer to his paper.

metrically measured, is 1680 feet above the sea; others stand at estimated heights of from 1780 to 1880 feet. Further up the Thompson a terrace, again barometrically measured, was found at 1600 feet, and a second, well defined, estimated at 1900 feet. These are no doubt the same as the two last mentioned. On the Bonaparte river (tributary to the Thompson), four miles north of Cache Creek, a terrace estimated at 2820 feet occurs, and further on, at Maiden Creek, one barometrically measured at 2680 feet. On ascending the plateau beyond Clinton (already mentioned) ill-defined "Boulder-clay terraces" are seen, in some places, above 3000 feet*. On entering the Thompson Valley the material of the terraces becomes much finer and more argillaceous than on the lower Fraser. In some places several hundred feet of nearly horizontal clay beds are exposed in transverse ravines, and seem to form the material of the terraces running along the sides of the valley. The lower terraces, which are always the best-preserved, are seen in many places to spread quite widely, and their deposits (shown in sections both parallel and transverse to the valley) to lie in beds nearly horizontal, or with a slight sag towards the centre. Individual gravel beds can sometimes be traced in the banks for a mile or more.

Carefully noting the aspect of the terraces in ascending the Fraser and Thompson rivers, which flow in the main-drainage valley of the great interior of British Columbia, tracing them from point to point with scarcely any break, and upward to the higher streams and most secluded nooks among the mountains, where denudation has been least effective, the conclusion is forced on the mind, that, while many of the higher are accumulations along the shore of a great sheet of water, most of the lower have been carved out of deposits which at one time filled the valleys from rim to rim, and more or less completely levelled up the broken surface of the country, by the gradually receding waters of a lake or of the sea, and eventually by the rivers themselves deepening their channels to their old Preglacial levels.

Moraines.—In some cases it is not easy to distinguish between certain fragments of high-level terraces and old lateral moraines. Much doubt may also obtain with regard to the origin of moraine-like forms when in the last stages of degradation from subsequent water-action and subaërial decay. A further difficulty is frequently found in British Columbia in ridges simulating moraines, formed where successive slides have taken place in great beds of drift-deposits surrounding rivers and lakes. Disregarding, however, all cases in which there can be the least doubt, there still remains abundant evidence of the great extension of glaciers from the present mountain-centres, and their sporadic appearance in many parts of the highlands and hills of the plateau. These appear to be the

* The terraces above enumerated occur in the vicinity of the main waggon-road. The measurements lay no claim to accuracy, being in many cases merely eye estimates aided by the known elevations of certain localities and the barometer. They may serve, however, to show the succession met with in travelling inland.

last indications of glacial action on a large scale, and to have been followed by the retreat of the ice to its present limits.

There are, however, a few cases where some traces seem to remain of older moraine-like accumulation, which, whether due to glaciers proper or to pack-ice, are probably of the date of the north-to-south ice-movement which the rock-striation proves to have occurred. The most marked instance of this I have seen is in the broad depression between the Il-ga-chuz and Tsi-tsutl volcanic ranges, through which the upper part of the Salmon river flows northward. These ranges, as before mentioned, lie transverse to the general direction of the plateau-country of the interior. The depression between them is about fifteen miles in width, and is thickly heaped with material not unlike the general Boulder-clay covering, but arranged, with greater or less regularity, in mounds and ridges with general east-and-west bearings, separated from each other by intervening swamps. In the lowest part of the depression the Salmon river cuts through a steep gravelly ridge which, though tortuous, has a general course about N. 70° E., and runs for a mile and a half or more. This may be of the nature of an esker; but, from its association with the morainic ridges above, in which the size of the boulders quite precludes this explanation, this does not seem probable. If water-borne ice, whether iceberg or pack-ice, be supposed sufficient to account for the north-and-south glaciation of rocks, these and other moraine-like accummulations may represent localities where heavy ice stranded and forced up bottom-material; while in places more exposed to open water and less to great accumulations of ice, shingle-deposits, like those described on Fort-George trail, may have been in process of formation.

Of the later outflow of ice from the present mountain-systems, I have had most opportunity of studying the traces of that which moved eastward from the Coast or Cascade range. It is evident, however, that a similar movement must have occurred from the Selkirk and Gold ranges and Rocky Mountains, though perhaps not to so great an extent, as the precipitation of moisture in these regions is much less.

The glaciers moving eastward from the Coast range appear in all cases to have followed the present river-valleys pretty closely; and though they must have overlapped the higher country in some places, it is in the immediate vicinity of the great transverse depressions now occupied by the rivers that their traces are most evident. Naming these valleys in succession from south to north, but without entering into particulars, the main facts may be stated as follows:—

Nicola Valley.—The river flows westward; but the drift-material, consisting of boulders and gravel, is largely, in some cases chiefly, composed of granitic and syenitic rocks derived from the coast-mountains, which have been carried eastward, and now overlie volcanic rocks quite different lithologically. This is the case to the lower end of Nicola Lake, where the drift assumes a more local character. No distinct moraines were observed.

Thompson Valley.—The river flows south-westward to its junction with the Fraser at Lytton. Fragments of the rocks of the Cascade mountain-series, in the form of large and small boulders, produce a rather irregular but evident moraine overlying rocks of a different character, twenty-four miles above Lytton.

The glacier, in both the above cases, must have crossed the deep valley of the Fraser; but the localities to which it has here reached can scarcely be said to be beyond the eastern flanking mountains of the Coast range.

Chilcotin Valley (lat. 52°).—Moraines can be traced here with certainty as far as the lower end of Tatla Lake, and with great probability to the outflow of Puntzee Lake. The former locality is situated twenty-five miles from the eastern base of the Coast range, and fifty miles from its central region; the latter forty miles from the eastern base. There is considerable reason to believe that the moraines of these places have been formed by a glacier pushing out into water, and somewhat modified by water-action, either contemporaneously or immediately after their formation. A congeries of small ponds, lakes, and swamps, called the Buckhorn Lakes, owes its existence to the steep-sided hollows, cup-shaped, trench-like, or crescentic, enclosed between moraine ridges. Many of these ponds have no visible outlets. A sheet of water six miles in length, called Eagle Lake, is dammed at its eastern end by moraine-material, in which very large angular blocks, evidently derived from low rocky hills at the sides of the valley, form a prominent ingredient. The watershed between the Homathco river, flowing directly through the Coast range to the sea, and branches of the Chilcotin, flowing eastward to the Fraser, lies just within the eastern foot-hills of the Coast range, is low, and apparently composed altogether of drift-material, more or less evidently morainic. It is probable that before the Glacial period the waters of a great extent of country now draining towards the Fraser, flowed by the gorge of the Homathco through the Coast range. Lakes and pools without outlet, irregular morainic hummocks and ridges, projecting to a greater or less height through flat or gently undulating deposits formed from their waste, characterize equally the sources of the east and west branches of the Homathco. A general movement eastward from the valleys of the mountains can be proved from the composition of the drift.

Blackwater and Salmon-River Valleys (approximate latitude 55°).—The tributaries of these rivers interlock about the 125th meridian, the former flowing eastward to the Fraser, the latter westward, through the Coast range. Moraines which appear, without doubt, to belong to the Coast-Mountain glaciers, occur beyond the low watershed on the tributaries of the Blackwater, at a distance of forty-five miles from the eastern base and sixty-five from the central peaks of the range. These are seen in the neighbourhood of Tsi-toe, Klootch-oot-a, and other small lakes of the same group. Sixteen miles further westward, at Uhl-ghak Lake, glaciation with a course of N. 80° E., evidently referable to this period, occurs. In the valley of the Salmon river, and in the nearly parallel one occupied by Tanyabunkut Lake (before referred to), moraines, in some cases nearly parallel to the sides of the valleys, in others more or less completely transverse to them, occur, with constant evidence of the carriage eastward in quantity, but not to a very great distance, of rock-fragments—granitic rocks, for instance, having been moved some miles eastward and left scattered on the glaciated surfaces of basalt-flows. The evidence of a previous movement of ice *westward* down the Tanyabunkut valley and towards the coast through the Salmon-river gap, owing to its sheltered position, has not been obliterated by the subsequent eastward flow, which all the evidence tends to show must have been of short duration.

South-western or Main Branch of the Nechacco River (lat. 53° 25′, long. 125° 10′).—The river here issues from a large lake called Na-tal-kuz by the Indians. The lake lies transversely in a range of hills which has a general north-west and south-east course, parallel to the Coast range and other main features of the country, but rising in the centre of a plateau region. To the south-east these hills become mountains about 2000 feet in height above the plateau in some instances. The lake is dammed by moraine-material with rocks appearing in its sides; and the surface of a small isolated rocky hill near its lower or eastern end shows heavy glaciation from west to east, parallel to the general course of the valley. East of the end of the lake the Nechacco cuts through a mass of moraines which covers a stretch of country probably at least five miles square. The moraines are very little modified, and wonderful in size and state of preservation (fig. 6). The most prominent form ridges miles in length, which, though wavering a little in direction and of variable height, sweep round to the north-eastward in broad curves, to the direction of which the river conforms for some time. The ridges are steep-sided, sloping frequently at an angle of 30° to the bottoms of the narrow sinuous valleys which separate them, and are from 100 to 200 feet in height. The best-marked ridges are evidently the successive lateral moraines of a glacier-tongue gradually decreasing in width. Besides these, however, there are occasional fragments of transverse ridges, blunter and broader, apparently remnants of terminal moraines formed when the glacier nearly equalled the valley in width.

It cannot be certainly affirmed that the glacier causing this display of moraines did not owe its origin to the low range above mentioned. Taking, however, all the local circumstances into account, and especially the small gathering-ground afforded by this range, it appears more probable that the Coast-Range glaciers must at one period have pushed a short distance through the gap in which the lake lies.

Still further north, on the 54th parallel, the valley containing, from west to east, François and Fraser Lakes and the lower portion of the Nechacco river, runs from near the eastern base of the Coast range to the Fraser in a remarkably direct line. François Lake, further west, is, by my track-survey, fifty-seven miles and three-quarters in length, with a width of from one to two and a half or three miles. It is slightly sinuous, the opposite sides generally remaining parallel, deep, and in part surrounded by steep hills, especially toward the lower end. The stream discharging François Lake runs eastward to Fraser Lake, eleven miles in length; and this, again, sends its waters by a very short stream to the Nechacco at its Great Bend. There is a remarkable absence of traces of ice-action in the valley of François Lake; and though both shores were carefully examined, no more certain sign of glaciation than the general form of some rock-masses was seen. The nature of the rocks may to some extent explain this; but the material of the lake-shore is remarkably local in character, being composed almost invariably of the immediately underlying rock. Following the valley eastward, however, at the lower end of Fraser Lake, on hard dioritic rocks, marks of very forcible glaciation are found. Ice has here evidently been pushing up out of the lake-bed, over a rock-surface, under great pressure, and has been forced in some instances through little rocky valleys at a considerable angle to its mean direction, which is remarkably constant at S. 88° E. to S. 93° E. On nearly vertical rock-faces on the northern side of the lake parallel grooving may be seen to run eastward, and slope upward at a considerable angle to the water-line. On flat surfaces near the shore, many instances of preglacial rock-hollows, with rough western and rounded eastern margins, were found. The glaciation continues apparent for some miles beyond the eastern end of the lake; and its direction is also shown by the fact that blocks of the diorites have been carried eastward until they overlie the newer basalts.

I do not think any of the hills bordering Fraser Lake reach an elevation of 1000 feet above it; and its western half is surrounded by low country. It is difficult, if not impossible, to account for the glaciation, unless it be supposed that a glacier stretched thus far from the Coast range, nearly one hundred miles distant. The absence of boulders from the mountains in the immediate vicinity of François Lake is singular; but that of the ordinary erratics, so plentifully distributed over all this region, is equally exceptional. These facts may perhaps be explained by supposing that the glacier swept the valley completely clear of the débris due to the earlier drift, while for some reason the material moving with the glacier itself was very small in amount.

This case and that of the Upper Nechacco do not give such indubitable proof of the action of ice from the Coast range as those before described in the region further south; yet, taking into account the circumstances in both instances, they scarcely seem explicable otherwise. From many other localities, however, in which moraines of greater or less importance are preserved, it would appear probable that at one time accumulations of ice sufficient to produce moraines by their movement lay as well on the more elevated portions of the interior plateau.

In all the moraines observed, the normal material differs little from that of the Boulder-clay; or when a difference obtains, it is in the direction of greater water-agency in its preparation. The stones are rounded and waterworn as a rule, heavily glaciated in a few instances, and mixed with large angular fragments only when these have been abundantly produced by some hill or cliff near at hand. There is also much evidence, especially about Tatla Lake, the Mazco watershed, and on the Nechacco, tending to prove that the gradually retreating glaciers piled up some, at least, of these gravelly moraines in water, which was decreasing in depth at the same time with the diminution of the supply of ice. This evidence is chiefly derived from series of flat-topped or water-wasted moraines in such localities and so arranged as entirely to preclude their being referred to esker ridges.

4. Mode of Glaciation and Formation of the Superficial Deposits.

In the foregoing I have endeavoured to give a short account of the glacial phenomena and superficial deposits of British Columbia, so far as I have examined them, entering into some detail in a few important and typical cases only, with the view of bringing the facts as they occur, in this hitherto little-known region, to the notice of geologists. Some uncertainty has been expressed as to the action on a large scale of glacial ice on the north-west coast of America, which may now, I hope, be removed, at least so far as regards British Columbia.

Professor Whitney, in the 'Proceedings of the Academy of Natural Sciences of California,' 1868, says that there is no evidence in California of a general glacial epoch, such as that which affected the Eastern States. He extends this conclusion to Nevada and Oregon, and, following information received from Messrs. Ashburner and Dall, further remarks that no evidence of northern drift has been detected even so far north as British Columbia and Alaska. Professor Dana, in the last edition of his 'Manual,' quotes Whitney's statement of the absence of northern drift, at least as far north as Oregon, but alludes to the grooving on Vancouver Island as possibly indicating general glaciation there. Professor Le Conte, however, speaks of northern drift near the Columbia river, east of the Cascade range *; while Gibbs writes of the country in the vicinity of Puget Sound, somewhat further north, that it is "one vast mass of modified drift" †, which he further asserts to have, at least in part, a northern origin, on account of the nature of the erratics. These must have been deposited in connexion with the southward extension of the Strait-of-Georgia glacier, or by floating ice after its retreat.

Dr. R. Brown, in a paper "On the supposed Absence of Drift on the Pacific Slope" ‡, combats the statements of Whitney and others, quoting especially Mr. Bauerman's observations on the coast- and

* Am. Journ. Sci. and Arts, March and April, 1874.
† Journ. Am. Geol. Soc. 1874.
‡ Am. Journ. Sci. and Arts, 1870, p. 318.

glacial phenomena which came under his own notice on Vancouver and as far north as the Queen-Charlotte Islands.

In regard to Alaska, Dall writes*, after describing his route across the breadth of that territory :—"I have carefully examined the country over which I have passed for glacial indications, and have not found any effects attributable to such agencies;" and again†, "Three years' exploration, with a strong disposition to develop the facts of the case, failed to obtain on the shores of Norton Sound, or in the valley of the Yonkon, any evidence whatever of such action." If Alaska has indeed escaped glaciation, while British Columbia and the adjacent regions have been so shaped by it, the fact is an extremely remarkable one. It must be observed, however, that Mr. Dall has failed to notice the evidence of glacial action in the inlets of the coast, and, indeed, affirms that no traces of such appear‡; while my own observations, confirmed and extended to a wider area by those of Mr. Richardson, show that glacier-work on a gigantic scale has occurred in them. In endeavouring to explain by any satisfactory scheme the sequence and cause of the phenomena, one meets with many elements of uncertainty and complication, arising not only from the very pronounced and varied physical features of the country, but from our as yet very imperfect knowledge of great regions of the interior. It may, however, be well to give such conclusions bearing on these points as a study of the region has enabled me to form.

There is little doubt that the glaciation from north to south is the earliest fact of the ice-age of which any record has yet been found; and the question arises as to whether this should be attributed to glacier-ice as such, or to floating ice. If to the former, it cannot be due to local action of any kind, as some of the localities where grooving is observed are elevated above the whole surrounding country, and the direction of movement required is contrary to the general inclination of the broken central plateau, and towards a region in the vicinity of the 49th parallel which is nearly blocked with irregularly traversed mountain-ranges. For reasons stated in a former investigation of the glacial phenomena of the Great Plains, I do not believe the theory of a polar ice-cap to be applicable to the western part, at least, of North America; but it must be confessed that the indications noted in some places in British Columbia more nearly answer to the kind of traces which such an ice-cap would be expected to leave than any thing I have elsewhere seen. The portion of the supposed ice-cap entering the central plateau must, however, be imagined to have passed as a preliminary across the mountainous region to the north of the Skeena and about the Findlay river, the Peace-river gaps lying obliquely to its course, and being besides not sufficiently large to admit the requisite quantity of glacier-ice, even if the pressure was so applied as to push it directly through the hollow.

* Am. Journ Sci. and Arts, vol. xlv. p. 96.

† "Observations on the Geology of Alaska," pub. in 'Alaska Coast Pilot,' 1869, p. 196.

‡ *Op. cit.* p. 195.

It is, however, possible that in one other manner a great glacier, moving from north to south, may have filled the central plateau. Owing to the warm water of the great Japan current, with the prevailing westerly and south-westerly winds and mountainous character of the coast, the annual precipitation of moisture is very great, especially to the north. At Sitka (southern end of Alaska) the average annual depth of rain and melted snow (from sixteen years' observations) is 82·66 inches, or within a fraction of seven feet; while the average number of days on which rain, snow, or hail fell, or heavy fogs prevailed, is two hundred and forty-five, or two days out of three. It may be supposed that, under certain not improbable combinations of conditions, the mountainous country to the north, above referred to, became preeminently the condenser of the Northern Pacific, and, from the mere accumulation of snow and ice, the focus of glacier-action and point of radiation of great glaciers. If the central plateau was ever filled thus by a great glacier-mass, the ice must have poured southward through the gaps on the 49th parallel, and westward across the Coast range, in a manner similar to that in which the ice supposed by Professor Geikie to have filled the Gulf of Bothnia must have crossed the Scandinavian peninsula*.

If the first glaciation of the central plateau is due to the action of glaciers as such, we should, however, expect to find remnants at least of deposits like those elsewhere ascribed to such gigantic ice-sheets, and not precisely resembling that noticed on a former page under the name of Boulder-clay. If these exist, they have not fallen under my observation; and in any case it appears necessary to call in the action of water with floating ice to account for the formation of the Boulder-clay, with its rounded pebbles and irregularly distributed erratics. It cannot have been laid down by glacier-ice; for it is difficult to imagine the formation of material which is found not only over plains but on exposed hill-slopes and summits, beneath a great glacier which we find in other places engaged in scooping rock-basins in the bottoms of valleys. It rests immediately on the well preserved glaciated surfaces, and, on the above suppositions of an extension of the ice-cap, or great central-plateau glacier, may have been formed during the gradual retreat northward of the decaying front of the ice while the country was submerged to a depth of over 5000 feet, either by access of the sea, due to general depression, or by the formation of a great lake covering the plateau region, the passes of the Coast range—those to the south, and those of the Rocky Mountains to the east, being still blocked by local accumulations of glacier ice. The movement of icebergs would explain the irregular distribution of the foreign mixed materials of the deposit. Water-action, sufficient to account for the rounding of the pebbles, may have occurred; and the gradual diminution of the glaciers in the various mountain-ranges may be supposed to have allowed the slow drainage of the lake, and given rise to the great systems of terraces.

* Great Ice Age, p. 404.

The stoppage of all the gaps to so great a height, however, in the various ranges would imply a coordination scarcely within the bounds of probability; and on grounds which are stated in the preceding pages, and others which will shortly be referred to, it appears to me more probable that it was by depression of the land as a whole, or elevation of the ocean, that the waters attained the level they are known to have reached in the interior.

To explain the facts by the action of floating ice, icebergs or pack-ice must be supposed to have entered the central plateau by the low gap through the Rocky Mountains in the Peace-River region, and, reinforced, no doubt, by ice from local glaciers, to have travelled southward under the influence of currents, which found exit by the Fraser river-valley and other southern openings. A depression of 3000 feet would open a wide strait from the Arctic Ocean to the Pacific, by the valleys of the Peace-River country, continued southward by that of the Fraser; while sea-water standing at a height equal to the maximum above stated would give depth enough for very heavy ice, and would besides open other avenues in the Rocky Mountains, and many and wide ones through the Coast range and to the south. If such palæocrystic ice as that met with by the late Arctic Expedition may be supposed to have filled the central basin, it will not be necessary to invoke the action of icebergs to account for the simultaneous, or nearly simultaneous, production of the north-and-south grooving, and deposition of the Boulder-clay. It is worthy of mention that in most places where striation referable to this system occurs, the country to the north is low, suggesting that the localities may have formed islands on the southern margin of a sea in which great ice-pressure may have occurred from time to time.

On the supposition of a submergence of three thousand feet or more, very important results might follow with regard to the distribution of ocean-currents. The Kamtschatka branch of the warm Japan current would, no doubt, be greatly augmented in size, and flow north-eastward through a widened Behring's Strait, possibly accounting for the apparent absence of glacial traces in Alaska. The outflow of ice-laden polar water would be to the same amount increased, causing a wide arctic current to flow southward in the region now forming the Mackenzie river-valley. A part of this would find exit across the great plains and by the Red-River hollow, while a second branch, traversing the Rocky Mountains by the Peace-River gap, would flow down the length of the plateau of British Columbia, accounting for the great transport of material and heavy glaciation found to have occurred in both these regions.

On any of the above theories the second advance of glaciers from the various mountain-ranges must be supposed to be the last phase of which we have any record. These glaciers appear to have pushed out among the water-rounded materials of some of the lower terraces, after a period of somewhat greater warmth, and before the reelevation was complete, or while a lake, or series of lakes, dammed by glaciers existed. The latter is not an unreasonable supposition when the comparatively small height of water required at this period is taken into account. As these latest glaciers retired, after their short advance, the waters also appear to have fallen, the partly water-modified moraine-mounds remaining as evidences of this joint action.

If glaciation of the mainland by a great northern ice-cap, whether of polar origin or arising within the country itself, ever occurred, Vancouver Island and the region of the Strait of Georgia must have been buried under a still greater accumulation of ice; but if the glaciation of the continent was effected during a submergence of 4000 or 5000 feet, very little of the island would remain above the surface of the sea, and the hollow between it and the Coast range would be below the level and sheltered from the action of the floating ice. In either case, however, the dimensions attained by the glaciers during their latest extension, taking into account the favourable position with regard to gathering-grounds of the Strait of Georgia, would appear to be quite sufficient to explain the formation of the great glacier of the Strait.

The supposed general submergence of the region to a maximum depth of 5270 feet may at first seem a very startling hypothesis, though it may be softened by such reference to its insignificance when compared with the diameter of the globe as that used by some of the advocates of a great northern ice-cap. It may, however, I think, be said to have been shown in the course of a former examination of the facts of glaciation of the Great Plains to be extremely probable, if not absolutely certain, that the whole interior of the continent, from the Laurentian axis to the Rocky Mountains, was submerged, and that the sea reached a height of at least 4400 feet on the flanks of the latter range*. With this terrace, and some of those described by Dr. Hector, those of Tatlayoco Lake, in the Coast range of British Columbia, correspond as closely as can be expected, taking into account the distance apart of the two localities (500 miles). Is it, then, surprising that, in a region further north and better suited for their preservation, water-marks should be formed at a yet greater elevation of about 900 feet? To explain some of the features of the last Glacial period, we are called upon to reproduce mentally conditions of which we can scarcely hope to appreciate the magnitude; but it does not appear that even 5000 feet of water should be considered so vast a conception as the like thickness of glacier ice. In Eastern America few localities present themselves where the effects of subsidence to an amount equal to this can be studied. We find terraces, however, to a height of 1425 feet on the Laurentian axis †; and it is worthy of remark that a depression of about the amount above indicated would serve to account for the glaciation and erratics of the higher mountains of the New-England states.

* Quart. Journ. Geol. Soc. vol. xxxi., 1875, p. 603; 'Geology and Resources of the 49th Parallel,' p. 244.

† Geology and Resources of the 49th Parallel, p. 256.

5. Summary.

1. The character of the rock-striation and fluting on the south-eastern peninsula of Vancouver Island shows that at one time a great glacier swept over it from north to south. The glacier must have filled the Strait of Georgia, with a breadth, in some places, of over 50 miles, and a thickness of ice near Victoria of considerably over 600 feet. Traces of the glacier are also found on San-Juan Island and the coast of the mainland.

2. The deposits immediately overlying the glaciated rocks, besides hard material locally developed, and probably representing *moraine profonde*, consist of sandy clays and sands, which have been arranged in water, and in some places contain marine shells. These, or at least their lower beds, were probably formed at the foot of the glacier when retreating, the sea standing considerably higher than at present.

3. Observations in the northern part of the Strait of Georgia, and the fjords opening into it—where the sources of the great glacier must have been—show ice-action to a height of over 3000 feet on the mountain-sides. The fjords north of the Strait of Georgia show similar traces. Terraces along the coast of the mainland are very seldom seen, and have never been observed at great elevations.

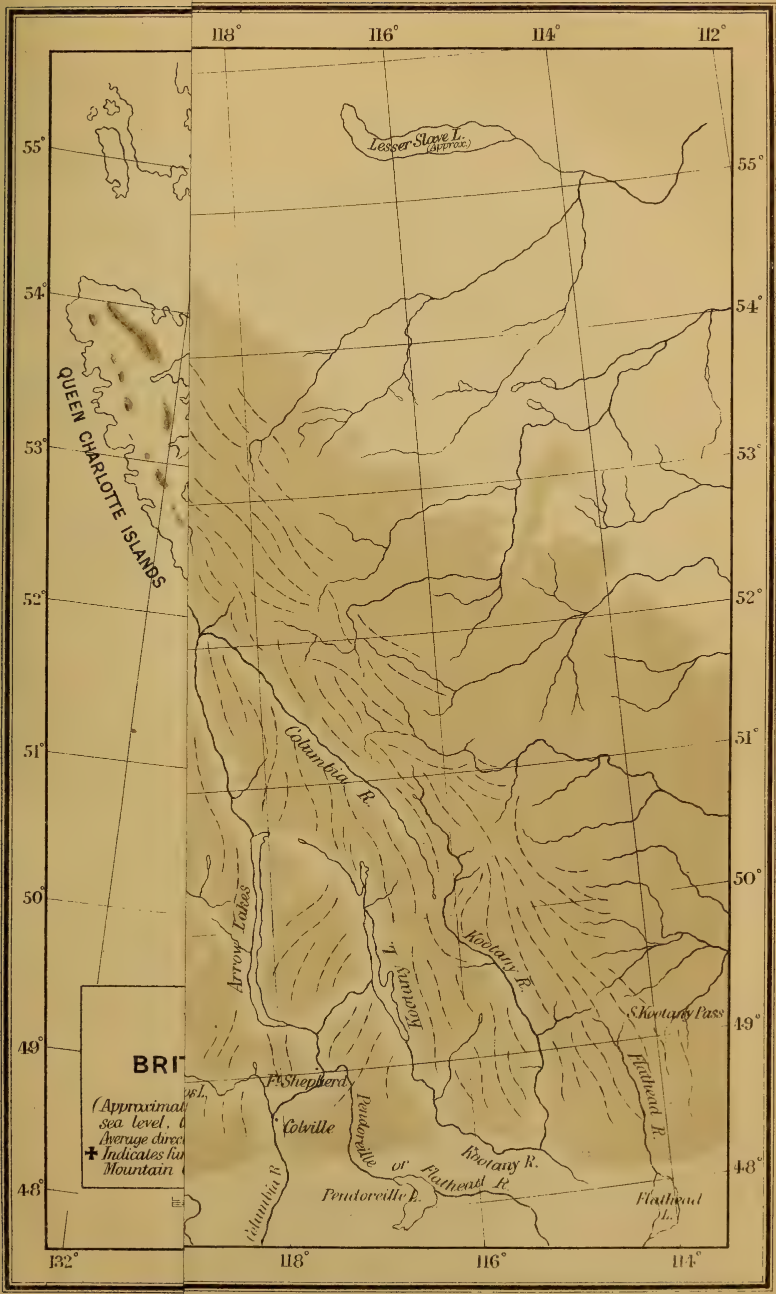
4. In the interior plateau of British Columbia there is a system of glaciation from north to south, of which traces have been observed at several localities above 3000 feet. Subsequent glaciation, radiant from the mountain-ranges, is also found.

5. The superficial deposits of the interior may be classified as unmodified and modified. The former, representing the Boulder-clay, hold many water-rounded stones, with some glacier-marked, and occurs at all heights up to over 5000 feet. The latter characterize nearly all localities below 3000 feet, and are most extensively developed in the northern low country, where they appear as a fine white silt or loess.

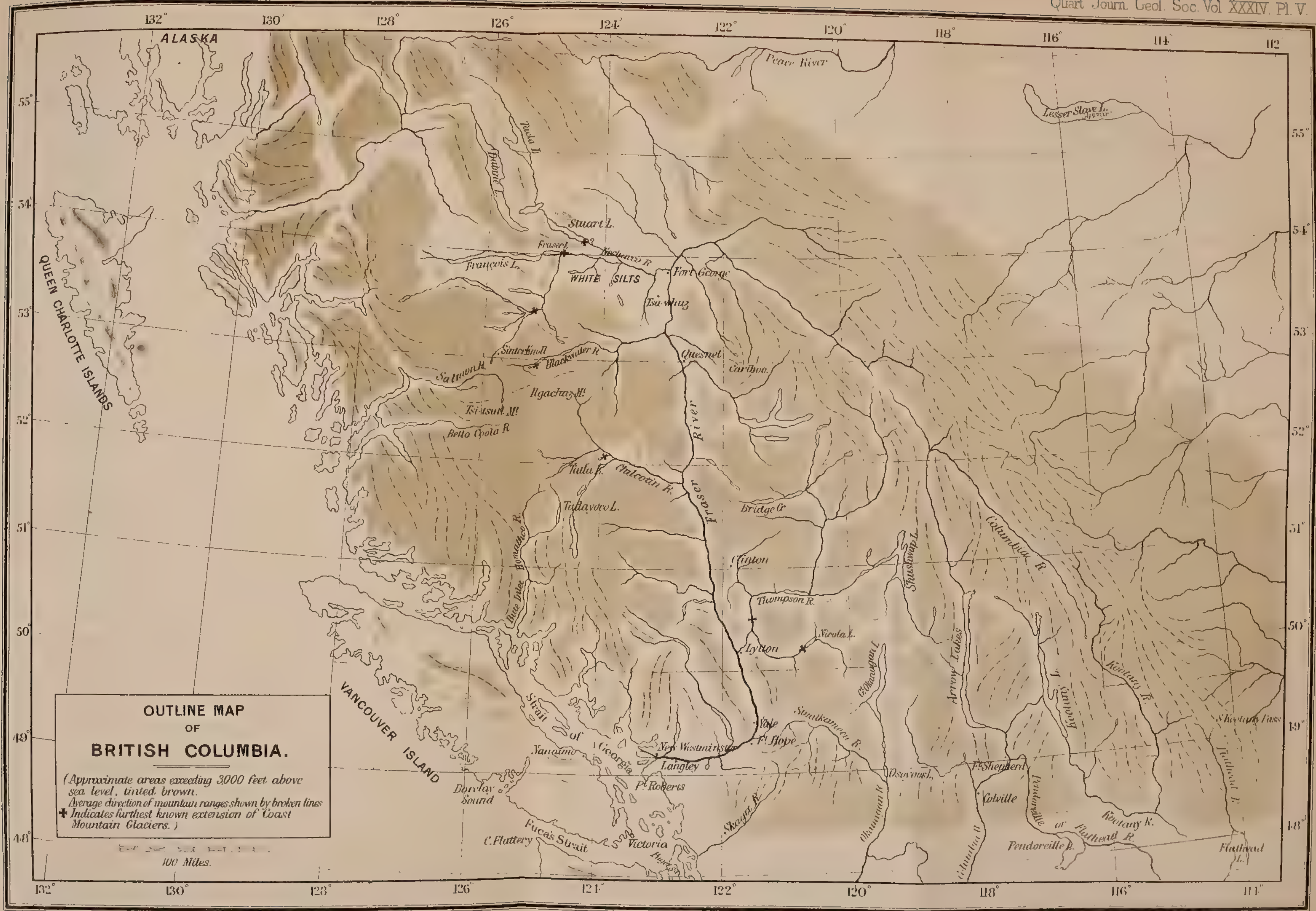
6. The interior is marked with shore-lines and terraces from the present sea-level up to 5270 feet, at which height a well-marked beach of rolled stones occurs on Il-ga-chuz Mountain.

7. Moraines occur in great numbers. Some of the moraine-like accumulations may have been formed in connexion with the north-to-south glaciation. Most of those now seen, however, mark stages in the retreat of glaciers towards the various mountain-ranges. The material of the moraines resembles that of the Boulder-clay, but with water-rounded stones even more abundant.

8. The sequence of events in the interior region has been:—glaciation from north to south, with deposit of Boulder-clay; formation of terraces by lowering of water-surface, accompanied or followed by a warm period; short advance of glaciers from the mountains contemporaneously with formation of lower terraces; retreat of glaciers to their present limits. Glaciation of Vancouver Island may have occurred during both the first and second cold periods, or during the second only.



DANGERFIELD. LITH. 22. BEDFORD ST. COVENT GARDEN.



Sanglefield Lith. 22 Bedford St. Covent Garden

9. If the north-to-south glaciation has been produced by glacier-ice, it must have been either (*a*) by the action of a great northern ice-cap (against which grave difficulties appear), or (*b*) by the accumulation of ice on the country itself, especially on the mountains to the north. In either case it is probable that the glacier filled the central plateau, and, besides passing southward, passed seaward through the gaps and fjords of the Coast range. The Boulder-clay must have been formed along the front of the glacier during its withdrawal, in water, either that of the sea, or of a great lake produced by the blocking by local glaciers of the whole of the valleys leading from the plateau, to a depth of over 5000 feet.

10. If general submergence to over 5000 feet be admitted, the Japan current would flow strongly through Behring's Strait, and over part of Alaska, while arctic ice-laden water, passing south across the region of the Great Plains, would also enter the central plateau of British Columbia, accounting for the north-to-south glaciation and simultaneous formation of the Boulder-clay.

EXPLANATION OF PLATE V.

Outline Map of British Columbia, showing the portions exceeding an elevation of 3000 feet above the sea-level, the general direction of the principal mountain-ranges, and the former extension of glaciers from the Coast Mountains.

10. *On* ARGILLORNIS * LONGIPENNIS, *Ow., a large* BIRD *of* FLIGHT, *from the* EOCENE CLAY *of* SHEPPEY. By Prof. OWEN, C.B., F.R.S., F.G.S., &c. (Read December 19th, 1877.)

[PLATE VI.]

THE fossils on which the above genus and species of extinct bird are propounded were discovered in the London Clay of Sheppey Island, and form part of the collection of W. H. Shrubsole, Esq., of Sheerness-on-Sea, by whom they have been kindly submitted to me, with permission to take casts of them for the Geological Department, British Museum.

They consist of parts of fractured humeri, the right and left, of the same species or individual, and include the articular head of the bone, with portions of the upper and lower parts of the shaft. They are in the usual petrified condition of the Sheppey fossils, more or less impregnated with pyrites, and, from the fractured and abraded condition of the more prominent parts of the bones, seem to have been subject to the forces of transport and rolling.

The texture of the shaft, the thinness of the compact outer bony wall, and the large size of the obviously pneumatic cavity, recall the characters of the wing-bones of the large Pterodactyles of the Cretaceous period. This leads me to refer to the 'Supplement' No. iii. to the Monograph on the Cretaceous Pterosauria (Palæontographical Society's volume, 4to, for 1860), in which descriptions and figures are given of the proximal portion of the right humerus of *Pterodactylus Sedgwickii*, Ow., a species about the size of a large vulture (*Vultur monachus*, L.), of which bird comparative views of the answerable bone and part are added in the same plate (pl. iii.).

A comparison of figs. 1–3 (Plate VI.) of the present paper with figs. 1 and 2 of the plate cited will show the difference of the Eocene fossil from the Cretaceous one; a similar comparison with figs. 6–8 of plate iii. Monogr. cit. will show the avian characters of the Sheppey specimen.

In giving the results of comparisons with the humerus in different kinds of birds, I avail myself of the same terms indicative of aspect and position as are defined in that Monograph. *Proximal* signifies the upper, *distal* the lower end of the bone as it hangs in Man. In the natural position of the humerus, as at rest, in Birds, the distal end is usually higher than the proximal one. When the palm of the hand is turned forward in the pendent arm of Man, the corresponding surface of the humerus is "palmar," the opposite surface is "anconal;" the outer side of the humerus is "radial," as being that which the radius holds; the opposite or inner side is "ulnar." The answerable surfaces or aspects bear the same names in the humerus of the bird. "Proximad," "palmad," &c. are adverbial inflexions,

* ἄργιλλος, clay; ὄρνις, bird.

meaning "toward the proximal end" and "toward the palmar side" of the bone.

In the proximal end of the humerus, figured in Plate VI., the following parts are noted:—

a. Articular head.
b. Radial tuberosity (answering to the "greater tuberosity," or *tuberculum majus*, of anthropotomy).
c. Ulnar tuberosity ("lesser tuberosity," or *tuberculum minus* of anthropotomy).
d. Scapular groove, lodging the lower border of the glenoid surface of the scapula (part of the "neck of the humerus" of anthropotomy).
e. Ligamentous pit or surface, receiving the anterior coracoid ligament.
f. Subtuberous fossa, with "foramen pneumaticum."
g. Radial border of ditto.
h. Tricipital ridge.
i. Pectoral crest.
k. Ancono-deltoid ridge.
l. Distal radial border of humerus.
m. Prebrachial depression.
n. Ectepicondylar process.

The subject of figs. 1–3 includes, of the left humerus, the articular head (*a*), the base of the radial tuberosity (*b*), that of the ulnar tuberosity (*c*), with the intervening scapular groove (*d*), the beginning of the tricipital crest (*h*), and that of the pectoral crest (*i*). In what remains of the subtuberous fossa part of a pneumatic foramen (*f*) is preserved; a greater proportion of the pneumatic fossa is shown in the right humerus (fig. 3, f').

The head (fig. 3, *a*), or proximal articular surface, is, as usual, elongate and moderately convex in the radio-ulnar direction, more convex across the shorter ancono-palmar diameter. It is characterized by its large relative size as compared, for example, with that in the albatross (*Diomedea exulans*), *ib.* figs. 4–6; and differs from the humerus in that and other birds in the degree and extent of the concavity longitudinally, or in the direction of the long axis (fig. 3, a') at the radial third part of the surface. The humerus of the Marabou (*Ciconia marabou*, Temm.) offers a feeble approach to this character.

The radial or outer tuberosity (*b*) has lost its outer layer; the cancellous structure is exposed by abrasion. The rising or smooth ridge (fig. 2, *h*), continued from the anconal part of the tuberosity upon the shaft below, is better marked than in *Vultur monachus*, still more so than in the marabou, pelican, and albatross, in which it is barely definable. The ulnar or inner tuberosity (*c*) is bent anconad, leaving a (scapular) groove or canal (*d*) between it and the head, wider and shallower than in the vulture, marabou, crane, and pelican, but less wide and shallow than in the albatross (fig. 4, *d*). Of the shape and extent, however, of this tuberosity the worn and fractured state of the fossil prevents a judgment.

The palmar part of the head (fig. 1, *a*), though abraded, projects further over that surface of the shaft than in any other bird with which I have compared the fossil. In the extent of the flat expanded surface so overhung the fossil is remarkable. The albatross, again, most nearly resembles it in this character, but without the overhanging production of the head (compare figs. 1 & 5). The smooth outer crust of this surface is impressed in the fossils with minute points, and shows very faint longitudinal striæ.

There is a trace of the foramen pneumaticum (fig. 2, *f*) at the bottom of the fossa beneath the ulnar tuberosity, the walls of the fossa being broken away.

The thinness of the compact outer wall of the shaft (with the concomitant wide air-cavity), and the size and conformation of this part of the wing-bone, bespeak a bird of flight, and a species as large, at least, as any of the existing birds which enjoy the characteristic locomotion of the class.

The portion of the right humerus includes, with the head (fig. 3) and indications of proximal structures above described, five inches of the shaft. From a preserved breadth of 2 inches it diminishes to that of 10 lines at the fractured end. The smooth ridge noted in the left humerus (fig. 2, *h*) is continued distad for 2½ inches before subsiding.

With the head of the left humerus were brought three portions of a long limb-bone with the pneumatic structure of the humerus in longipennate birds of flight (Pl. VI. figs. 9 & 10), and corresponding in size with the portion of the shaft of the right humerus, but less crushed and distorted.

The first of these portions I infer to be from the proximal half of the shaft; it is three-sided, with the angles broadly rounded off, but least so at that angle which shows the base of an outstanding ridge. An inch and a half of this base or origin is preserved (figs. 7 & 8, *i*), continued from the proximal fractured end of the bone. I infer it to be part of the origin of the "pectoral crest." Anconad of this origin, and about 3 lines distant therefrom, is a linear ridge (fig. 7, *k*) running longitudinally parallel therewith, and bending slightly more anconad before terminating at the distal fractured end of the portion. This ridge denotes the insertion of the *ancono-deltoideus*, or "posterior deltoid muscle."

Now, as to the trihedral shape of this proximal portion of the humerus, which may include one fourth or one third of the shaft, such shape is not shown by the humerus in the majority of birds: I find it in certain Raptores, Longipennates, and Totipalmates. In all that do show it one of the sides is palmad, the other two sides are anconad (as in figs. 7, 13). In the eagles and vultures (*Vultur monachus*, Monogr. cit. pl. iii. fig. 7) the angle dividing the radial from the ulnar sides of the anconal surface is sharper than in *Argillornis*.

Pelecanus and *Diomedea* come nearest to the fossil in the obtuseness or degree of rounding-off of that angle, but fall short of that degree shown in the fossil. In all the characters above compared, the portion of shaft (fig. 7), like the head of the bone (Pl. VI. fig. 1), is from a left humerus.

The next character which I find available in steering toward the port of determination is the linear ridge above mentioned, viz. the "ancono-deltoid ridge." It varies, in different birds, in its relative position to the pectoral ridge. In Raptores it is relatively closer to the base of that ridge than in *Argillornis*. In *Pelecanus* its relative position agrees better with that of the ancono-deltoid ridge in the fossil, but it inclines distally toward the radial border of the bone instead of from that border. In *Diomedea* both its course and relative position (fig. 13, *k*) at the part of the base of the pectoral ridge answering to that preserved in the fossil best agree therewith; but there is in *Diomedea* a second linear intermuscular ridge (*ib. k'*) anconad of the first, of which there is no trace in the fossil.

But the sum of my comparisons of the present portion of humerus inclines me to see the nearest affinity to be to the longipennate natatorial or aquatic birds, and among them to the largest existing kind, viz. the albatross (*Diomedea exulans*), but with a difference of size indicated by the subjoined admeasurements:—

	Argillornis. lines.	*Diomedea.* lines.
Transverse breadth of humerus at distal termination of the origin of the pectoral ridge	12	9

A guiding modification of the distal portion of the humeral shaft in birds is the difference of form of the radial and ulnar sides of the bone. The radial side becomes, in most birds, the narrowest, as the shaft descends and expands toward the distal articular end; and in the albatross it is carried to the extreme of becoming a mere ridge for near 3 inches from that end (figs. 14, 15, *l*). The portion of the distal end of the shaft of the present fossil humerus, wanting the articular termination of the bone (figs. 10–12), presents this character, and, as in *Diomedea*, shows the narrow longitudinal groove on the palmar side of the ridge (fig. 11). This groove is the radial border of the triangular flat and shallow depression (figs. 11, 15, *m*) for the origin of the "brachialis anticus" muscle, which depression shows the usual linear roughness or sculpturing due to such relation of muscular attachment. The same sculpturing marks the triangular "prebrachial depression" (fig. 11, *m*) in *Argillornis*; but the triangle is longer and narrower in the fossil, and the free surface of the palmar part of the shaft, ulnad of the depression, rises more abruptly from it in *Argillornis*, and presents a more uniform transverse convexity than in *Diomedea*.

Unfortunately the characteristic ectepicondylar process (fig. 15, *n*) of *Diomedea* has been broken away, if it ever existed in *Argillornis*, with the rest of the distal end of the humerus in the present fossil (fig. 11); but it may be remarked that the presence of such a projecting part of the humerus, like the pectoral and subtuberous ridges in *Diomedea* (figs. 4 & 5, *c'* & *i*) would render the rolled fossil more liable to such fracture and loss.

In relation to other species and genera of birds based on fossil remains from the London Clay, the cranial evidence of *Dasornis londinensis* * indicates a bird too big to be upborne by wings of a size to which the present fossil bone would belong; and, besides, the characters of that fossil skull were rather those of a large flightless or ground-bird. The skull of *Odontopteryx*, on the other hand, seems too small in proportion to the humerus of a bird exceeding in size that in *Diomedea*.

It is much more probable that the avifauna of the Eocene period should supply a palæontologist with many more species than he has already determined, than that so singular a form should have existed as a bird with a head of the size of that of the Solan goose and wings of vaster expanse than those of the albatross. The sternum of the still smaller Eocene bird, *Lithornis vulturinus* †, at once removes that genus and species to a distance from *Argillornis*.

The humerus of *Pelagornis miocœnus*, Lartet ‡, of similar size to that of *Argillornis*, differs, as far as its mutilated state permits comparison, in the form of the articular head and the narrower scapular groove.

In *Pelagornis* the head is relatively small and less prominent proximally than in other birds; the transverse ligamentous groove (*e*) is well marked, as in Totipalmates; the bicipital surface is very narrow, and develops below a tuberosity more prominent than in the Boobies (*Sula*), but not projecting beyond the ulnar border of the shaft; the ulnar tuberosity is large and projects anconad.

Prof. Seeley § refers an ornitholite in the Woodwardian Museum to the *Lithornis emuinus* of Bowerbank, and accepts its supposed emuine or cursorial affinity, with the remark:—"Taking the ostrich as a type, this bird diverges from the typical *Struthionidæ* on the other side of the emu, yet appears to conform to the Casuarine allies;" and he proposes to refer the fossil to a genus *Megalornis*.

If the Woodwardian fossil should prove to have formed part of the longipennate volant bird, the subject of the present paper, I would refer to the 'Proceedings of the Zoological Society of London,' February 1843, for the following entry:—"A communication from Prof. Owen was read, proposing to substitute the name *Dinornis* for that of *Megalornis*, applied to the Great Bird of New Zealand in his paper read at the previous Meeting. The change is rendered desirable to prevent confusion in nomenclature, Mr. George Gray having previously used the term *Megalornis* for a genus of Birds in his 'List of Genera' &c." To this notice the Editor adds a foot-

* Trans. Zool. Soc. vol. vi. p. 144.

† 'British Fossil Mammals and Birds,' 8vo, 1846, p. 549, fig, 232. One of the fossils described in the present paper had a label attached, with the name *Lithornis emuinus*; if the specific name referred to *Dromaius*, the evidence of the size of wing and concomitant power of flight renders the reference of such fossil ('Comptes Rendus de l'Acad. des Sciences,' 6 Avril, 1857) to the Australian struthious genus inappropriate.

‡ Alph. M.-Edwards, 'Oiseaux Fossiles de la France,' 4to, 1868, pl. xlv.

§ Seeley, "Note on some new Genera of Fossil Birds in the Woodwardian Museum" (Annals and Magazine of Natural History, 1866, 3rd ser., vol. xviii. p. 110).

note:—"This change in the name has been made in the paper referred to whilst passing through the press."

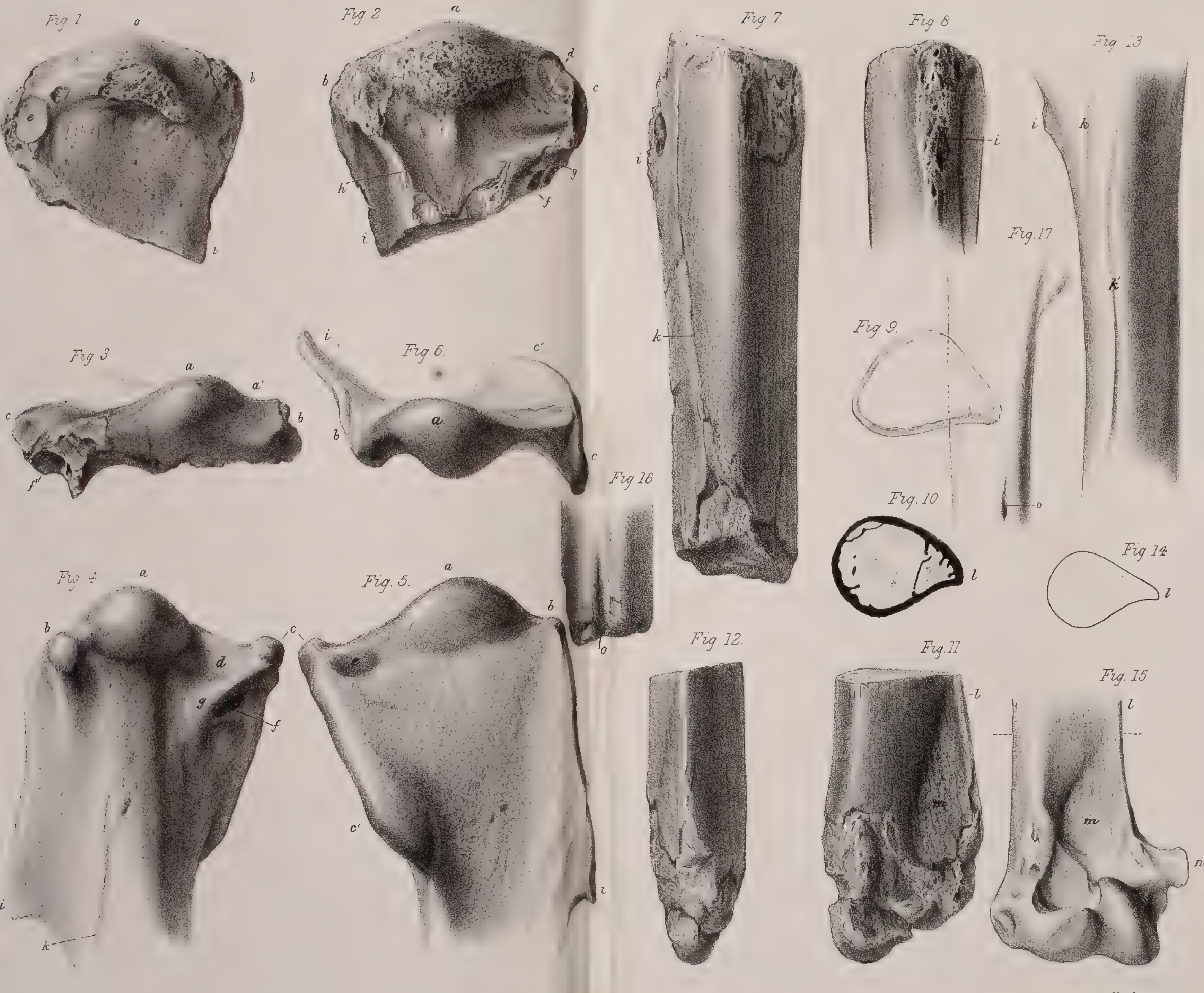
EXPLANATION OF PLATE VI.

Fig. 1. *Argillornis longipennis.* Proximal end of left humerus, palmar surface.
2. The same, anconal surface.
3. Proximal end of right humerus, proximal surface.
4. *Diomedea exulans.* Proximal end of left humerus, anconal surface.
5. The same, palmar surface.
6. The same, proximal surface.
7. *Argillornis longipennis.* Proximal portion of the shaft of left humerus, anconal surface.
8. The same, radial border.
9. The same, transverse section distad of pectoral ridge, showing size of pneumatic cavity and of its compact wall.
10. Distal portion of the shaft of left humerus, transverse section above *l*, fig. 11.
11. The same, palmar surface.
12. The same, radial border.
13. *Diomedea exulans.* Proximal portion of shaft of left humerus, anconal surface.
14. The same, transverse section distad of pectoral ridge.
15. Distal end of left humerus, palmar surface.
16. *Argillornis longipennis.* Ulnar side of distal end of fig. 7, showing a groove, *o*, leading to the pneumatic cavity.
17. *Diomedea exulans.* Corresponding side of fig. 13, showing the groove leading to the "foramen arteriæ nutritiæ" in *Diomedea.* This additional evidence of the humeral nature of the portion of bone of *Argillornis* (fig. 7) was detected and pointed out to me by the accomplished artist Mr. C. L. Griesbach, F.G.S.

Discussion.

Prof. Seeley said that it was impossible to form a judgment upon the matters brought forward by Prof. Owen without an opportunity of closely examining the specimens. At the same time he had no doubt that the remains were those of a bird; and he had himself, several years ago, obtained in the same locality a bone (a cast of which he exhibited) which he regarded as part of the tibia of a very large bird, and referred to a genus which he called *Megalornis.* At the time that his paper on this specimen was written, he was not aware that the name had been already appropriated, although he had consulted competent ornithologists on the subject. With regard to the specimens described by Prof. Owen, there might perhaps be some doubt whether all of them belonged to the fore limb, since two of them, he thought, closely resembled parts of a tibia such as the tibia of *Megalornis.* If this resemblance were not an accidental coincidence, the remains exhibited might furnish indications of two genera.

The Author, in replying, remarked that the bone which Messrs. Bowerbank and Seeley had held to be "tibial," and of an Emuine or wingless bird, was "pneumatic," therefore part of a bird of flight. But if tibial, the proportions of the humerus of such a bird would far exceed those of the fossils exhibited and referred to that bone. Prof. Owen then pointed out in the supposed tibial fragment intermuscular ridges which, with the more obvious characters he had described, would receive from palæontologists the same interpretation as his own.



C.L.Griesbach lith. Hanhart imp

ARGILLORNIS LONGIPENNIS, (*Figs.* 1_3, 7_12 & 16.) AND DIOMEDEA EXULANS, (*Figs.* 4_6, 13_15 & 17).

11. *On the* Circinate Vernation, Fructification, *and* Varieties *of* Sphenopteris affinis, *and on* Staphylopteris (?) Peachii *of* Etheridge *and* Balfour, *a Genus of Plants new to British Rocks.* By C. W. Peach, Esq., A.L.S. (Read May 9, 1877.)

(Communicated by R. Etheridge, Esq., F.R.S., V.P.G.S.)

[Plates VII. & VIII.]

In May 1874 I found *Sphenopteris affinis* in the "blaes" used to make a small railway for a new oil-shale pit at West Hermand, near West Calder, in the county of Edinburgh. It was rather abundant; and with it was a small "flower-like plant" quite new to me. These I exhibited on the 14th of that month to the Members of the Botanical Society at Edinburgh, and gave a short notice of them, of which a very brief abstract appeared in their 'Transactions,' vol. xii. p. 162, 1874. Feeling much interested in these finds, and desirous, if possible, to work out the new plants, I resolved to visit the place as often as I possibly could, and was frequently very fortunate in getting specimens of both plants. These were generally shown to the Members of the Botanical Society at their Meetings.

Last year I had found such good specimens that I wrote a short notice; this, with some drawings and specimens, I read before the Natural-History Section of the British Association at their Meeting at Glasgow, and, by request, to the Geological Section. Of the new plant no one appeared to know any thing. A very short abstract of my paper will appear in the forthcoming 'Transactions.'

On my return from the Glasgow Meeting I again, in October, visited West Calder; and, from knowing the best spot for the fossiliferous "blaes," I was most fortunate, indeed, in securing specimens, far better than any I ever had before, both of *Sphenopteris* and *Staphylopteris* (?), with so much that was new that I now venture to submit it and the specimens to the notice of the Society through my kind friend Mr. Robert Etheridge, Palæontologist of the Geological Survey, Jermyn Street, London. Before proceeding further, I think it right to mention what came of my showing the specimens to the Botanical Society here. Mr. R. Etheridge, Jun., Acting Palæontologist of the Geological Survey of Scotland, called my attention to the Report of the Geological Survey of Illinois, in which certain plants named *Staphylopteris*, found in the Carboniferous rocks of Arkansas, are figured and described by Leo Lesquereux, and said he thought mine might belong to that genus.

Professor Balfour, at the June Meeting, 1874, as recorded in the 'Transactions of the Botanical Society of Edinburgh,' vol. xii. p. 176, stated "that the fossil plants exhibited by Mr. Peach" (at the May Meeting) "seemed to belong to the genus of Ferns called by Presl *Staphylopteris*. Species had been found in the Tertiary formations of Europe. Leo Lesquereux had also detected specimens in the

Coal-measures of North America; these had been named *Staphylopteris Wortheni*, *S. asteroides*, and *S. sagittatus*; and are described in vol. iv. of the 'Geological Survey of Illinois.'"

"The fructification of *Staphylopteris* seems allied to that of *Botrychium* or *Aneimia*. It consists of small rounded or elliptical sporangia opening at the top, apparently by numerous valves. If the species observed (by Mr. Peach) has not been described, it ought to bear the name of the discoverer." The specific name had been previously suggested by Mr. R. Etheridge, Jun., who pointed out another species, named (also by Leo Lesquereux) *Staphylopteris stellata*, from Arkansas.

A short time ago I obtained access to a paper by Stur, "Die Culm-Flora," published at Vienna, 1875, where, at plate xvii. fig. 2, is the figure of what he calls the "Fruchtstand eines unbekannten Farnes." This "Fruchtstand" is much like some of mine—in fact, I believe, *identical*. I shall allude to this again when I describe my diagrams and specimens, and show how far it agrees with or differs from them.

Sphenopteris affinis.

I now enter upon the history of *Sphenopteris affinis*, and, as I go on, will show the new points in its history that have occurred to me. The first notice of this plant is in 'The Fossil Flora' of Lindley and Hutton, pl. xlv. The figure is that of a pinna, and gives a very poor idea of the beauty of this elegant Fern when at all perfect. A better representation of it is the restoration by the late Hugh Miller, given as a frontispiece to his 'Testimony of the Rocks.' One thing is wanting to it: instead of the base of the stem being rounded only and not thickened, it should bulge out like an onion, with delicate rootlets from the underside.

This form I have seen in several specimens of fossil Ferns, and in a set of recent ones collected in Australia by Mr. Robert Grieve. In following up my finds connected with *Sphenopteris affinis*, I met with it in *circinate vernation*, and in this state got it from the earliest stage to the completion of the frond (see Pl. VIII. figs. 6 & 7). These specimens are in the British Museum.

One thing more I felt anxious about was *fruit*. I had occasionally seen what I considered such. This continued up to October 1876, when I met with a small portion of a frond, well marked; it was lying amongst, but not attached to, masses of *Staphylopteris* (?). I still wanted better examples; and on again examining my stores I found a *noble one full of fruit*, collected on the 8th of May 1874. The splendid fructification on it had hitherto been overlooked by me; but it is so fine and good, that I now speak with confidence. The spore-cases lie in rows; and these run lengthways on the back of the fronds between the strong rib-like veins, generally in single, occasionally in double rows (Pl. VII. fig. 2). This state is *very rare* in the Ferns of the Carboniferous formation.

This Fern occurs in great variety, differing greatly; and there is no doubt that some of these varieties have been made new species of.

To help to set this to rights, I have taken portions of the plant out of the matrix, and placed them in glass, so that they may be well seen. In addition I send specimens in shale, to show how greatly it varies, and also what a magnificent Fern it must have been. I regret that these are so fragmentary. The "blaes," when exposed, are rendered so friable by wet and sun that they fall to pieces. How many fine and good specimens has it been my lot to see crumble to pieces in my hands when trying to secure them!

This Fern must, in some instances, have been two feet high. In two of the specimens sent will be seen the onion-like base, one with rootlets. *Sphenopteris affinis* is the Fern of the Calciferous Sandstones in and around Edinburgh. It is abundant at West Hermand, West Calder; next so at Burdiehouse, in the Limestones. The one figured by Lindley and Hutton came from this quarry. At Slateford and at Grange Quarry, near Burntisland, it is rather rare. It is also occasionally found in the *Iron-stone nodules* amongst the shales at Wardie and the other places mentioned.

STAPHYLOPTERIS ?

Having given references to works in which this genus has been described and figured by foreign botanists, and also what has been already said about the Fern found in this country and named *Staphylopteris*(?), I will endeavour to describe it more fully.

First, I feel it right to say that I have great difficulty in describing the "flower-like part." "*Spore-cases*" does not altogether fit it; for, although I have searched carefully and tried all means, up to the present time I have not *seen a single spore or any thing like one*, nor the vestige of a leaf, *nor fern-like frond*, nor star-like form and trailing thread-like stem creeping along a broad plant, such as are figured *from Arkansas*; and so I must use "flower-like form" until something turns up that will be better for it. The one most like mine, as before mentioned, is the "Fruchtstand" figured by Stur in his 'Die Culm-Flora,' pl. xvii. fig. 2, from Altendorf, as the description of the little one he figures, *so far as it goes*, will perfectly fit my "flower-like forms." I give a free translation of it, made by my son, of the Geological Survey. "The two twigs of a very fine stem, from Altendorf, bear on each tip a slightly open cup-shaped seed-vessel. The right-hand one is about half-open at the tip, where can be seen the four pointed ends of the cup. The left-hand one shows a cup somewhat wider open, while the upper ends of the tips scarcely appear so pointed."

I may just mention that, besides the *Staphylopteris* (?) in the Calciferous Sandstone, I have met with at least four or five other plants, evidently of the same species as those found in the Culm formation of Altendorf. One or two of these are, I think, new to British rocks; and therefore I have little hesitation in saying that the plants from the Culm formation, as described by Stur, are very closely allied to, if not identical with those of the Calciferous Sandstones of Scotland; and this encourages me to believe that his "Fruchtstand" and my "flower-like forms" are one and the same *species*. At present I am doubtful about the genus, and hence the ? mark.

I now add a further description of my new plant. The "flower-like forms" *hang* generally on slender twisted stems, in pairs, several of these often clustering together (see Pl. VIII. figs. 1 & 2). Occasionally the "flower-like forms" are rounded and nearly smooth. The divisions of these, when rubbed down, show the internal structure: this is surrounded by a carbonaceous border, black and shining; a line also of the black matter runs partly up the centre of *one*; in the *other* it is pressed to one side; the remainder of the vase is filled with iron pyrites. *There is not the least appearance of spores.*

Each "flower-like form" is about $\frac{1}{8}$ inch over, and fully that in height. Some show seven divisions (or little vases); the divisions, however, vary both in size and number, according as they are well or otherwise preserved. The little vases are very much wrinkled and pressed flat. In one instance, in *an iron-stone nodule* (Pl. VIII. fig. 3), I found them plump and rounded, and very finely striated only*.

The stems in *immediate connexion* with the "flower-like parts" are very slender; the others vary considerably: some are tolerably broad and long.

In Pl. VIII. fig. 4 I have given the upper end of a "flower-like form" which has been pressed down in an irregular manner, and hence the form. This shows that, when perfect, *it was cup-shaped*; nothing of structure is seen in the central part (shale only), *nor spores in any part of it.* The vase-like divisions are as if covered with scales; this is owing to the nearly *vertical pressure.* On the same slab another has been similarly pressed, but not so well preserved.

In one specimen the "flower-like forms" may be seen singly, and their attachment to *Staphylopteris* (?); and it is interesting to see the delicate, pendent, twisted and flexible stems clothed with the "flower-like forms," and as well the small triradiate stems amongst them, all well contrasting with the stout, straight, bifurcating ones of its supporter, *Sphenopteris.* As the *Staphylopteris* (?) increases in growth, the "flower-like forms" get into large masses, and the triradiate stems become long, broad, and strong. These masses, on close examination, show that they are made up of little clusters of the "flower-like forms" perched on furcate delicate stems; each of these clusters is again fixed, in an umbellate form, on single stout stems, and these last to a stouter single footstalk, much like the corymbs of elder-flowers.

In another case I find a little group (mass-like) of the "flower-like forms" laid on their sides like hands with the fingers stretched out, well showing the *Staphylopteris* (?)-form; it also is nearly surrounded by triradiate stems. I have slabs of stems of *Staphylo-*

* The opened "flower" has *seventeen* points (vases?); this, however, must be received with caution; so many may be owing to the parting of one or two by pressure.

pteris (?) and *Sphenopteris*; many of those of the former are triradiate, and at times assume different forms according as they are fixed. One of the stems is partly studded with small wart-like protuberances; these appear to communicate with the stem of *Sphenopteris* to which it is fixed; and the same occurs in other instances.

In addition to triradiate stems, "flower-like forms" are scattered about with portions of the supporting stem of *Sphenopteris* and a few detached portions of its fronds and leaves. In one instance we have a splendid *Sphenopteris* similarly surrounded, but with more delicate stems and "flower-like forms;" there are, however, two interesting examples of the mode of attachment of *Staphylopteris* (?) to *Sphenopteris*, showing a disk-like form laid on the stem of *Sphenopteris*, with delicate rootlets springing from it and folding round the stem.

A piece of shale which shows the finest example of triradiate stem I have ever found, flat and broad, and throwing out smaller crooked stems at the ends, with "flower-like forms," is especially interesting, some of the stems having passed *through the shale*, and thus the plant had flourished on both sides. This passing through laminæ of shale has occurred to me several times.

Another fact should not be passed over: wherever *Staphylopteris* (?) is met with, there is *Sphenopteris* also; the latter (*Sphenopteris*), however, is very frequently, in fact most frequently, found where not a vestige of the "clinger" is to be seen, clearly showing that *Sphenopteris* thrives without *Staphylopteris*. There is another curious fact: whenever *Staphylopteris* (?) is in contact with *Sphenopteris*, the latter is found to be denuded of its fronds, and often the stems are in a shattered state, showing sickness and death. Portions of the shattered parts often lie in the same slab, but not attached to the *Sphenopteris*.

Under these circumstances the question often occurs to me, "Is *Staphylopteris* (?) a *parasite* or an *epiphyte*?" If either, we could easily understand the forlorn state of *Sphenopteris*, it having, like the tares, nettles, hemp, &c. of the present day infested by *Cuscuta*, been strangled or otherwise destroyed. The "flower-like forms" of *Staphylopteris*, with the twisted and contorted (often screw-like) stems, shrivelled and furrowed, remind me so much of *Cuscuta* that I feel it difficult to avoid thinking (but "*thinking*" is not allowable) that there is some relationship between the ancient and modern "clingers." Then another question crops up: "What about the triradiate stems?" I can only refer to those of the Mistletoe. One curious fact on this head: I have never found *Sphenopteris* when in youth and beauty *so* clothed with *Staphylopteris* (?)—*only* when, to use a nautical phrase, "under bare poles." I must now leave these questions to be decided by the scientific palæontologist. One thing I will try to do, if my lease is further renewed, find more and better specimens, and, if possible, some that will tell either yes or no. Whatever *Staphylopteris* (?) may be, I never saw a trace of it on any thing but *Sphenopteris*, although several other plants are in the same rocks where it is found.

Conclusion.

Staphylopteris (?) has been found by myself in the "blaes" (once in an ironstone nodule amongst the "blaes"), rather plentiful at West Hermand, West Calder; by Mr. Bennie, fossil-collector for the Geological Survey of Scotland, in shales at Currie, near Slateford; at Straiton, near Burdiehouse, in a piece of shale at the oil-shale pit, by Mr. D. J. Brown, of Edinburgh, and Mr. Bennie. All these localities are in the Calciferous Sandstones of the Carboniferous formation of Scotland.

All the diagrams were made by myself from specimens I collected. I send, with two exceptions (which are in the British Museum, but were also collected by myself), all the specimens figured; so that the Members can see for themselves how far they are to be trusted.

One more remark. None of the American specimens of *Staphylopteris* agree with the British one; and thus Professor Balfour's wish as to species has been carried out.

EXPLANATION OF PLATES VII. & VIII.

Ferns from the Calciferous Sandstone Series of Edinburgh.

Plate VII.

Fig. 1. Frond of *Sphenopteris affinis*, Lindl. & Hutt., nat. size.
1 *a*. Portion of the same, × 4.
2. Another portion, showing fructification, × 4.
2 *a*. The same, nat. size.

Plate VIII.

Fig. 1. *Staphylopteris* (?) *Peachii*, "flower-like parts," × 4. 1 *a*, nat. size.
2. The same, a bunch of "flower-like parts," × 4. 2 *a*, nat. size.
3. The same, a single "flower-like part," × 4. 3 *a*, nat. size.
4. The same, a single "flower-like part" flattened, from above, × 4. 4 *a*, nat. size.
5, 6, 7. Circinate vernation of *Sphenopteris affinis*, slightly enlarged.

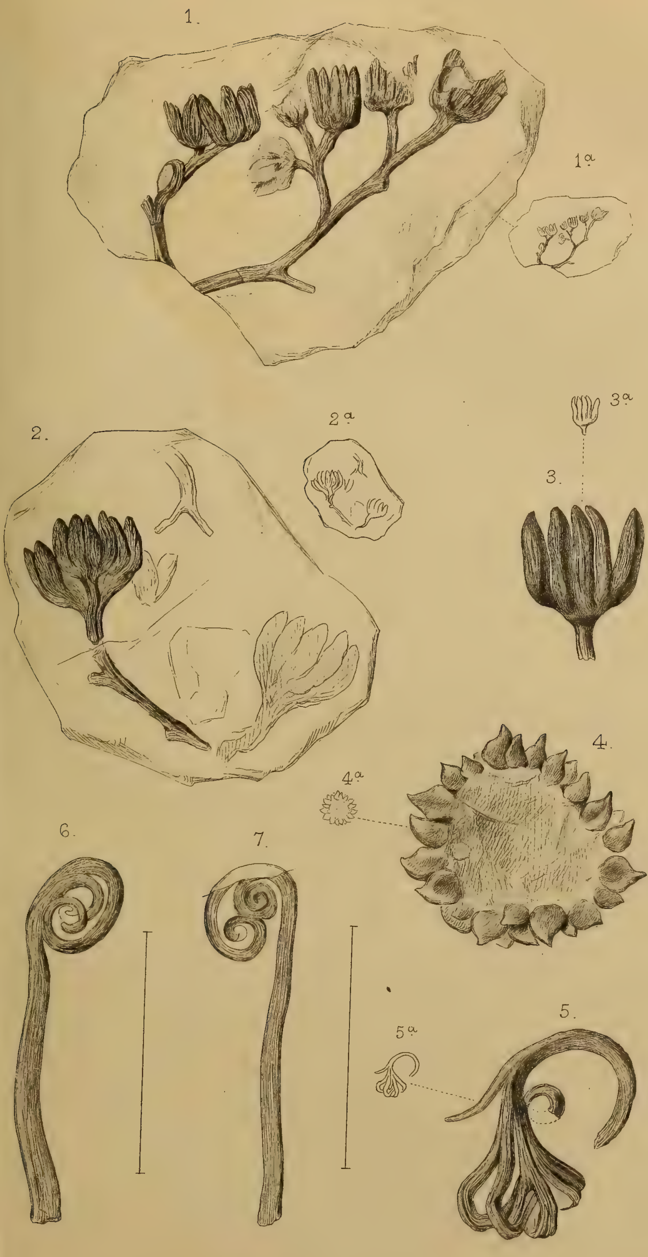
Discussion.

Mr. Carruthers spoke in high terms of appreciation of Mr. Peach's work in nearly all departments of Natural History. The greatest credit was due to him for his exceedingly careful observations. At the same time, Mr. Carruthers was compelled to differ from him with regard to the plants which had been brought before the Society on this occasion. The structure of the fruit in some of Stur's coal-plants is the same as in the living *Hymenophyllum*, consisting of two valves peculiarly arranged, the lower pinnæ of the fronds being fertile and modified accordingly. The same thing seems to have occurred in *Sphenopteris affinis*, except that the lower pinnæ retained their normal structure, and the apical pinnæ were modified as the fruit-bearing portion, which had been regarded as forming the peculiar genus *Staphylopteris.*

C. L. Griesbach lith.

Mintern Bros. imp.

SPHENOPTERIS AFFINIS.
From the Calciferous Sandstone Series.



Griesbach lith.

Mintern Bros imp.

STAPHYLOPTERIS (?) & SPHENOPTERIS.
From the Calciferous Sandstone Series.

12. *On the* Pre-Cambrian Rocks *of* Bangor. By Prof. T. McKenny Hughes*, M.A., F.G.S. *With a* Note *on the* Microscopic Structure *of some Welsh Rocks*, by Prof. T. G. Bonney, M.A., F.G.S. (Read December 5, 1877.)

In a paper entitled "Outline of the Geological Structure of North Wales," read before the Geological Society, June 21, 1843, and published in abstract in the Proc. Geol. Soc. vol. iv. pp. 212–224, Prof. Sedgwick gives a general sketch of the Cambrian rocks from the Bangor and Caernarvon series to the Bala beds. The general character he describes as follows :—"The rocks occupying the region are chiefly composed of *felstone* (compact felspar) and felstone porphyry, trappean conglomerates, plutonic silt (exactly like the chloritic varieties of German *Schaalstein*), and other erupted or recomposed igneous products; and the above-named rocks alternate indefinitely with fine masses of roofing-slate, and with great masses of greywacke—and with greywacke slate, often calcareous, but rarely containing beds and masses of limestone" (p. 215).

Further on he states that "the group of chlorite, slate, &c. contains no organic remains, and forms no passage into the rocks of the other division; it therefore offers no sure means of classification; but it seems to be inferior to the other slate-rocks in the southern promontory of Carnarvonshire" (p. 219). Passing over these, and "commencing with the line of the Nant Francon and Llanberis slate-quarries, the author (Prof. Sedgwick) describes a series of regular ascending sections, continued through a horizontal distance of three miles," *i. e.* up into the Bala beds.

In a subsequent paper, read before the Geological Society, Dec. 16, 1846, and published in the Quart. Journ. Geol. Soc. vol. iii. p. 133, though it is clear he has not yet worked out his subdivisions, nor made up his mind as to the value of some tentative correlation of beds not seen in continuous sections, he shows that he has got hold of the fact that the Bangor beds are not an altered state of the Lower Cambrian, but a distinct underlying series. He says, p. 136, "In short, the slates near Bangor and Carnarvon are among the very oldest rocks of North Wales; of course," he adds, "excepting the crystalline and hypozoic groups of Anglesea and of the S.W. shore of Carnarvonshire, which I do not at present wish to notice." "On the shore near Bangor they alternate with Trappean conglomerates and Trappean shales (Schaalstein)." He points out that the series is "traversed by the railway-tunnel, that it is interrupted by two great ribs of porphyry, which he considered intrusive; but he says that these Bangor and Caernarvon beds are repeated in symmetrical undulations towards the base of the higher mountains of the Caernarvon chain, and thinks that the second great rib of porphyry very nearly resembles in position and structure the more

* For the discussion on this paper see p. 165.

western rib of syenitic porphyry" (p. 137)—pointing out that the beds of its upper surface are of such remarkable structure, and offer such apparent passages into the overlying slates, that he cannot in all the quarries separate one formation from the other (p. 137). Subsequently, in a paper read before the Geological Society, Feb. 25, 1852 (Quart. Journ. Geol. Soc. vol. viii. p. 146), he says that he had not found a well-defined base for the Cambrian series of North Wales, unless we take the metamorphic rocks as a kind of hypothetical base, and gives the following descending series:—

Arenig slates and porphyry.
Tremadoc slates.
Lingula flags.
Harlech grits.
Llanberis slates (including slates, grits, and bands of porphyry).
Metamorphic series.

By this time the Geological Survey was at work in North Wales, and Jukes was in correspondence with Sedgwick. So we find speculations as to why the Lingula flags had not turned up where he expected them, and at last the announcement that the Survey had found them. This settled the correctness of Sedgwick's correlation of beds in that district. Subsequently, however, Prof. Ramsay arrived at the conclusion that the altered rocks of Llyn Padarn, which had been referred by Sedgwick to an ancient formation beneath his Cambrian, were not a distinct underlying series, but the frizzled ends of beds of Cambrian age, which were seen in an unaltered state close by; and in confirmation of this view it was pointed out that the conglomerates taken as the base of the Cambrian dipped towards the metamorphic axis. This opinion was published in 1866 in Memoirs Geol. Surv. vol. iii., and is illustrated by sheets 28 and 31 of the cross sections of the Geological Survey.

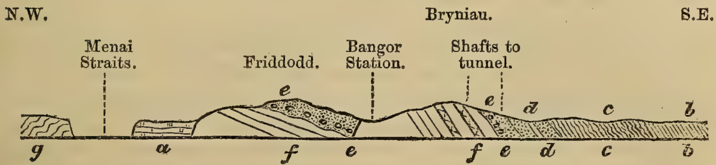
In 1868 Mr. Maw described "a new Section of the Cambrian Rocks in a cutting of the Llanberis and Carnarvon Railway" (Geol. Mag. March 1868, vol. v. p. 121), about halfway along which he considered that there was a visible unconformity in the lowest part of the series of Cambrian rocks, where a "dark green rock," which he had been following, "suddenly terminates, resting," as it seemed to him, "on the upturned edges of an older slate."

By this time the Laurentian, Labrador series, and Huronian of America, and the fundamental gneiss of Scotland, had been assigned to their true position below the Cambrian; and some of the metamorphic rocks of Norway, and of various isolated areas in the British Isles, were beginning to be suspected to be of earlier date than Cambrian. So geologists were prepared to accept the views of Mr. Salter and Mr. Hicks as to a Pre-Cambrian island at St. David's. It was, however, pointed out that the coarse conglomerates, which seemed to form a more natural base for the Cambrian, did not rest immediately on what was at first defined as the Pre-Cambrian Island, but on a higher series of bedded rocks, fragments of which could be identified in the Cambrian conglomerates.

It still remained for Mr. Hicks to work out this district; and the results of his investigations led him to infer that there were at St. David's two distinct formations underlying the Cambrian, and, as he considered, unconformable to it and to one another.

In the 'Records of the Rocks' (1872, p. 28 *et seq.*) the Rev. W. S. Symonds expressed the opinion that many of the crystalline rocks of North Wales and other districts "belong to a more remote age than that of the Cambrian formations, and that hereafter they will be classed as Laurentian or, at all events, as Pre-Cambrian."

Section near Bangor. (Length of section 2 miles.)



CAMBRIAN.
- *a.* Mountain Limestone.
- *b.* Black slate.
- *c.* Banded slate.
- *d.* Greenish grit and subordinate purple and green slate.
- *e.* Grit and conglomerate.

BANGOR BEDS.
- *f.* Greenish slates, hornstones, breccias, &c.
- *g.* Schists.

Referring to the above section it will be seen that black slates, exposed in various places between Llandegai and Pentir, S.E. and S. of Bangor, are followed in descending order to the N.W. by black-and-grey sandy shales with wavy white lines, and beds of gritty sandstone, and, on the whole, agreeing in lithological character with the Lingula Flags. The black slates above are on the strike, and probably about the horizon of the black slates exposed in a road-cutting and trial-shaft for coal about three quarters of a mile S.S.E. of Caernarvon, which are highly fossiliferous, and clearly of Arenig age (see Marr, Quart. Journ. Geol. Soc. vol. xxxii. p. 134). In the Bangor section the details of this part of the series have not yet been made out; so we can say nothing of Menevian. Below the Lingula Flags there is a considerable thickness of dark-greenish, gritty, chloritic rocks, in the lower part of which purple slates are here and there intercalated. Wherever the section is clear we find at the base of these a grey coarse grit, with hyaline quartz generally conspicuous, all weathering yellowish. This grit is almost always, partly or wholly, replaced by a coarse conglomerate, with pebbles up to the size of a man's head, but generally about the size of pigeons' and hens' eggs. The matrix is the same as the grit. These descriptions are from observations with the naked eye only. It is probable that the microscope would disclose many varieties of character, dependent on what part of the underlying series each bed was derived from. This section agrees in its general features with that seen along the shores of Llanberis and Llyn Padarn.

The conglomerate above described, from its hard nature, generally forms a ridge, and so is known to be almost always present at the base of the green and purple grit and slate series. It may be followed along the shore N.E. of Gored Gith, near Bangor, and can be seen at intervals striking S. across the ridge E. of Friddodd and W. of Bangor Station, with a general easterly dip.

It is then thrown about half a mile east by the N.E. and S.W. faults. The first place where I found it S.E. of the fault was in a road-section leading up from the city towards the Mount; it crops out on the hill known as Bryniau, and is pierced by the east shaft into the railway-tunnel, and is again seen in projecting ridges N.E. of Nant Gwtherin.

It occurs at intervals N.W. of Llanddeiniolen for about three quarters of a mile, associated with grits, striking N.E. and S.W., almost parallel to the Caernarvon road. It is seen by the road S.E. of Gorphwysfa, where it seems to be twisted over close to the fault, as if an anticlinal had been cut obliquely by the fault. This conglomerate is made up, as has been stated above, of pebbles in a gritty matrix. The pebbles consist of quartz-felsites, porphyries, a rock like a granite with no mica, all of which can be identified in the underlying series next to be described, and a quartzite, which I have not yet succeeded in finding in place among the undoubtedly underlying rocks, but which can be matched in a bed occurring among the mica-schists of Anglesey. The pebbles stand out conspicuously; and where the rock is weathered it falls to pieces, and can seldom be broken across the pebbles.

Under the grit and conglomerate, which seem to form everywhere the basement bed of the Cambrian, we have a series of stratified rocks, many of which are of a very marked character, easy to identify and trace, others variable and not very characteristic. Immediately to the W. of the east shaft to the tunnel, below the conglomerate, there are some greenish and purplish beds of schist and tough felsite, breaking with a conchoidal fracture, and ringing under the hammer. Below this there are several beds of breccia, and fine green slate, with the lines of bedding very distinctly marked, and often crossed by small faults healed by the later cleavage. The dip is about 58° S.E. Further to N.W. we cross some more green chloritic schists and schalsteins; but this part of the section is troubled by frequent greenstone dykes, and obscured by talus and remains of drift. Nothing is seen below the conglomerate by Gored Gith, as it there comes against the great fault, and seems to have got turned along it so as to form the cliff almost all the way to the baths near Garth Point. Along the road to Menai Bridge, however, beds of pale altered slate are seen, dipping as though they would pass under the conglomerate. In the corresponding position W. of Bangor Station we find, also dipping under the conglomerate, and, like it, at angles of from 40° to 50°, pale altered slates, below which a brecciated conglomerate is seen, having a very crystalline appearance; and below this there are more pale slates, with an altered grit, in which the quartz appears in sago-like granules. S.E. of Gorphwysfa the beds, which seem to pass under the conglomerate, are first pale altered slates, cut by a greenstone dyke, and below them a crystalline brecciated conglomerate. Over this area the balance of evidence is rather against there being any visible unconformity at the base of the Cambrian conglomerate, as it seems to be succeeded always in descending order by similar beds.

It is highly probable, to say the least, that a considerable fault runs from near Bangor Station almost in a straight line S.W. to where the railway crosses the more southerly of the two faults drawn in the Survey map. This will explain the N.E. and S.W. trend of the ridges of agglomerate seen near Traws Canol and Penrhos Garnedd, and would explain away some difficulties near Penychwynfan.

On the S.E. of the Bangor and Caernarvon road, that runs along the valley by the station at Hendre Wen, about half a mile S.W. of Bangor, there is a large quarry in which, following a greenstone dyke, they have exposed a thin bed of crystalline conglomerate, dipping N.W. About three quarters of a mile further to the S.W., near Taï'rffynnon, lenticular beds of pale altered slate occur in a purple brecciated conglomerate, dipping N.E. Hornstones and variously altered slates crop out near Tafarn Newydd; and beds of fine brecciated and ash-like deposits and grey or speckly granular altered rock are seen along the road near Tyddyn du; and near Brithdir there is a purple porphyry associated with a breccia. The relation of this to the associated beds I have not yet made out.

The bedding of the Pre-Cambrian rocks is so far well defined, and near Bangor, generally in an easterly direction, sometimes a little S., sometimes a little N. of E., but always oblique to or across the trend of the hills. When we get about a mile S.W. of Bangor, except in the bit between the two faults S.W. of the Station, the prevalent dips are N.E., *i. e.* quite across the ridge, and so persistent and high that we must infer a very considerable thickness of rocks, while the variations in their lithological character are such as to lead us to believe that it is a fair descending series, and not a repetition of the same rocks by folds. I will not, however, on such incomplete evidence, offer any more exact estimate of thickness.

This series can be matched almost bed for bed among the green slates and porphyries of the Lake District, and, like these, may be referred to an original volcanic origin and some subsequent metamorphism; but they do not present a sequence like the lowest part of the Cambrian, among which we find no beds that could by any process be changed into the alternating agglomerates and ashes of the Bangor volcanic series.

The included fragments are chiefly bits of the associated rocks, just as old lavas and other volcanic rocks at the present time get broken up and ejected in later eruptions. The finer slates are traversed by small faults, such as might be caused by shocks soon after their deposition, but which have been healed by the pressure which long afterwards produced the cleavage. So in the green slates of the Lake District we not unfrequently see three or four small faults shown on one slate.

Professor Bonney has kindly made a microscopic examination of some selected specimens, and given full notes of the results, which are appended, and quite confirm the view of the volcanic origin of the beds (Appendix, Nos. VII.–IX.).

Below the grit and conglomerate of Llanddeiniolen we do not find this great series of slates and agglomerates; but at a short distance below them we come upon the massive quartz felsite which forms the greater part of the ridge, and at the S.W. end we find this passing down into the coarser crystalline quartz-felspar rock of Caernarvon, which, as Prof. Ramsay remarked, but for the absence of mica, looks like a true granite (Mem. Geol. Surv. vol. iii. p. 162). There are, however, divisional planes and successive variations of lithological character, which make it highly probable that it is only an altered rock, though perhaps originally in part of volcanic origin; and the microscopic investigation of Professor Bonney appended (No. III.) makes this inference more sure.

As to the relations of the Cambrian, the Bangor volcanic series, and the Caernarvon quartz-felspar rock, to one another, there is much in the behaviour of the beds on Bryniau-Bangor to suggest that the conglomerate is transgressive across the edges of the volcanic series; and near Llanddeiniolen it appears to have overlapped the whole of the Bangor beds, and to rest on the upper Caernarvon beds, or quartz felsites; but whenever we get the two series in close juxtaposition, there is such a coincidence of dip and strike as to render the inference of unconformity from the mapping only, in that faulted district, at present unsafe; and, moreover, if the Bangor beds are a volcanic series, we must not depend upon this kind of evidence in proof of an unconformity, as we might if we had to do with ordinary marine sediment, like the Lingula Flags, for instance.

In the Llyn-Padarn section, especially, the fragments in the agglomerates are much rounded, so as to suggest that towards the close of the period of volcanic activity a larger and larger proportion of the volcanic ejectamenta got worked up by the action of the sea until at a subsequent (but perhaps not long subsequent) period they were all sea-washed and rolled, forming, with the waste of rocky shores, the coarse conglomerate we have taken as the base of the Cambrian.

This must be left for the present a doubtful interval, just as there is some doubt as to the relations of the Coniston or Bala limestone series to the old volcanic green slates and equivalent rocks in North Wales; but, notwithstanding all these difficulties and other possible explanations, it does seem to me that the balance of evidence is in favour of a considerable break between the Cambrian conglomerate and underlying Bangor series.

There is nothing to suggest any discordancy between the Bangor and Caernarvon beds; but on this point I have not much evidence to offer.

I will now endeavour to reconcile this interpretation with the observations of other authors on various similar districts, pointing out some modifications of their views which the results of my work lead me to suggest.

In the Llyn-Padarn section we have a more intense cleavage than in the Caernarvon and Bangor area, and a sharper folding of the beds near the base of the Cambrian; but as far as I could follow the section, it seemed to me that, where the conglomerate did not turn up again so as to pass over the porphyritic series, it always ended off at a fault or a greenstone dyke, which so often in that district runs along a fault. The conglomerate is too persistent in its occurrence along the flanks of the porphyritic ridge not to make the explanation that metamorphism *happens* to have stopped just there rather improbable. The observed metamorphism affects the rocks in vertical, not horizontal extension—*i. e.* in the now tilted beds is seen ascending through the beds, not extending along the same bed.

I feel sure, therefore, that the Cambrian conglomerate is the base of a distinctly overlying series, whatever we may be able to say as to its conformity and further relations to the volcanic series below.

With regard to Mr. Maw's view, that there is a visible unconformity in the greenish schists seen in the railway-cutting on the S. side of Llyn Padarn, his most carefully drawn and accurate section enabled me easily to find the exact spot referred to. I cannot, however, agree with his interpretation of the phenomena. The irregularity seemed to me to be due to lateral pressure acting on beds of unequal texture and character. The coarser and more sandy beds were crumpled and contorted, while the finer beds were compressed and cleaved, and, being thrust into the folds of the harder beds, gave the appearance of a denuded jagged edge of slaty rock, on which sand had been deposited, filling the clefts and notches. It would be very improbable that denudation, such as furnished the material of the Lower Cambrian beds, could have left such a surface; and a close examination of the junction shows that it is a larger case of what is common enough, on a smaller scale, in the very same district, where small beds of different texture are crumpled up together, one taking cleavage the other not.

A somewhat similar phenomenon may be seen close to the Dinorwic workshops at the S.E. corner of Llyn Padarn, where there is a large surface exposed of what looks at first sight like ripple-marks, but which seems to be really due to the edges of cleaved slate thrust into a thin parting bed of yellowish pasty rock, not more than three quarters of an inch in thickness.

There seems to be very good reason, from similarity of lithological character and correspondence in the sequence of beds, for correlating respectively the Bangor and Caernarvon series with the Pebidian and Dimetian of Mr. Hicks. But while the St.-David's section seems to me to strengthen the probability of an unconformity between the Cambrian conglomerates and the Bangor beds, as the distinction between the conglomerates and the agglomerates is more strongly marked in South than in North Wales, on the other hand it confirms the impression that there is no unconformity between the Caernarvon and Bangor beds, as it appeared to me that the upper beds of the Dimetian at St. David's (*e.g.* at Lower Moor, on the side of the valley running down from the cathedral) were distinctly brecciated, and so formed a passage into the more marked agglomerates of the Pebidian, while all the discordances involving conflicting strikes and dips were along valleys, in some part of which there were undoubted faults. Moreover it seemed to me that the green beds in the Dimetian were all dykes. The microscopic examination of the Lower-Moor rock by Professor Bonney leads him to the conclusion that it is a product of denudation (No. V.); and two of the green beds, Nos. I. & II., he would refer to altered basalts.

On the whole, then, it seems that we have an old volcanic series of remarkably persistent character in North and South Wales (and probably we shall find, beyond the borders, that subdivisions can be made out in it, though as yet no break has been proved in the series), and that the base of the Cambrian consists of a strong conglomerate and grit, between which and the underlying series there is great probability of an unconformity.

This is only working out the details of the classification published by Prof. Sedgwick thirty-five years ago.

Appendix.

Note on the Microscopic Structure of some Welsh Rocks.
By Professor T. G. Bonney, M.A., F.G.S.

No. I. *Dyke in Dimetian; east of Porthlisky, St. David's.*—The ground-mass of this rock consists of crystals of plagioclase, now greatly kaolinized, or replaced by secondary products, together with viridite, which is partly the normal isotropic mineral, partly the serpentinous form, showing, with crossed Nicols, a fibrous structure of a dull blue colour. This probably replaces an augitic constituent. There is a considerable quantity of magnetite, some calcite, visible, with probably much more finely disseminated and one or two crystals of a deep brown isotropic mineral, resembling picotite or a dark-coloured garnet. The rock, then, is a diabase.

No. II. *Band in Dimetian; Quarry by Church School, St. David's.*—An ill-defined ground-mass of minute plagioclase crystals (or their pseudomorphs) with dusty patches, resembling kaolin, and much fibrous viridite. In this numerous small grains of magnetite are scattered, with larger crystals, much altered, often more or less replaced by viridite: some certainly are plagioclase; but others may have been augite. Plagioclase, magnetite, and a little (?) apatite are now the only unaltered minerals. The crystals show a slight parallel structure; and some are broken, the fragments occasionally remaining near together, as though the rock, when almost solid, had been subjected to a strain or pressure. At present it must be called a diabase; it has been a basalt, and much resembles a flow in its structure.

No. III. *Lowest beds, Llysmeirion, Caernarvon* (p. 142).—A highly altered rock, consisting largely of quartz (dull in tint with polarized light, and containing many minute cavities and enclosures), with felspar, not very characteristic as to species, partly decomposed, and traversed by lines of minute secondary products, golden-coloured with crossed Nicols; also a little iron peroxide, and some vermicular or rosette-shaped aggregates of a slightly dichroic golden-green mineral, probably allied to chlorite. The quartz, in parts of the slide (which varies much in texture), is distinctly in broken grains, subangular in form; and the rock is certainly of clastic origin.

No. IV. *Felsitic Series N.W. of Llanddeiniolen, Caernarvon* (p. 142).—The ground-mass is a devitrified glass, showing in parts a fluidal structure very well, containing distinct crystals of felspar, sometimes of rather a broken aspect, and grains or imperfect crystals of quartz. There is also a very little iron peroxide, some minute secondary microliths, golden, as above, especially in the larger felspar crystals, where both orthoclase and plagioclase can be recognized. Three or four crystals, partly occupied by iron peroxide, show also a fibrous pseudomorph, rich-coloured with crossed Nicols, and are probably pseudomorphs after hornblende or mica; one or two crystals resemble decomposed ilmenite. The rock is probably from an old flow of rhyolitic lava.

No. V. *Coarse Breccia; Lower Moor, St. Davids.*—A highly altered rock, consisting mainly of quartz and felspar (both kinds), having a general resemblance to No. III. It is difficult to pronounce on the exact origin; but much of the quartz and felspar appear to be fragmental and more or less angular, while the texture of the rock seems to vary much. There is a fair amount of viridite, and but little iron peroxide. Some of the fragments show a graphic structure. The larger fragments do not come into the slide. I do not find any devitrified lapilli, and think this rock probably not one of volcanic origin, but formed by the denudation of a granite or granitoid gneiss, the fragments of which were soon deposited—like the "arkose" of Auvergne.

No. VI. *Brithdir, Bangor.*—A devitrified ground-mass, exhibiting flow-structure well, with many minute grains of iron peroxide, numerous grains and imperfect crystals of quartz, and crystals of felspar of both kinds, often with a broken aspect, not unlike some of those found in the Wrekin District. Devitrified rhyolite, probably from a flow.

No. VII. *Agglomerate. Pre-Cambrian; West Shaft to Tunnel, Bryniau, Bangor.*—Composed of fragments, very variable in size and nature, in a ground-mass resembling a fine felspathic dust, much altered; many secondary products, difficult to describe or name exactly. Larger fragments, quartz, altered felspar, slaty rock, and some lapilli, one or two showing plagioclase, which, however, are not very characteristic. The slaty fragments seem highly altered, and contain microliths, apparently felspathic and of secondary origin;

some of the viridite resembles a pseudomorph after augite or hornblende. The rock is probably pyroclastic; but the materials may have been transported by water to some little distance.

No. VIII. *The same.*—Fragments rather smaller, and rock more speckled. Ground-mass much decomposed, with a considerable quantity of a streaky green mineral, much of which, with crossed Nicols, shows a fibrous structure and rather bright colours, probably akin to serpentine. In this are fragments of highly altered felspar, of quartz (subangular), several lapilli of a devitrified trachyte, two showing grains of quartz *in situ*, and some bits of a slaty rock; also a few crystals of a dark-brown isotropic mineral, like an iron garnet, and a little (?) apatite. Like the last rock, probably pyroclastic; but perhaps the materials are a little rolled.

No. IX. *Banded Indurated Slate above the Agglomerate; Bryniau, Bangor.*—Ground-mass finely granular, brownish, rather decomposed (most of it dark with crossed Nicols), generally crowded with broken felspar crystals, with slightly banded arrangement, all very angular in form, much decomposed, probably generally orthoclase, several small lapilli of trachytic aspect, and a little magnetite or ilmenite. Like some of the finer banded slates of Charnwood Forest, this rock appears to be composed of volcanic dust.

To conclude: IV. and VI. appear to have belonged to lava-flows, and so render contemporary volcanic action very probable; VII.-IX. are, I think, conclusive on the point, the first two containing volcanic materials, even if they have been transported or mixed with others, and IX. being inexplicable to me if not a true pyroclastic rock.

13. *On some* Pre-Cambrian (*Dimetian and Pebidian*) Rocks *in* Caernarvonshire. By H. Hicks, Esq., F.G.S.* *With a Note by* Thomas Davies, Esq., F.G.S. (Read December 5, 1877.)

In consequence of the remarks made by Prof. Hughes in the discussions following the reading of my paper on the Pre-Cambrian rocks of St. David's on Nov. 22, 1876, in which he expressed the opinion that there was much reason for considering some beds passed through in the adit to the slate-quarry at Moel Tryfaen in Caernarvonshire, to be Pre-Cambrian, and also of the statement made by Mr. Maw in the discussion of my paper read on Dec. 2, 1874, that under the Cambrian rocks at Llanberis there are unconformable beds which may be the equivalents of the Pre-Cambrian rocks of St. David's, I determined last summer to examine these areas for the purpose of seeing whether there was sufficient evidence to support the above-mentioned supposition.

I was assisted in these examinations by Prof. Hughes, Mr. Hudleston, and Mr. Homfray, of Portmadoc, and am greatly indebted to each for much kindly help and advice. We first visited the neighbourhood of Moel Tryfaen, since it seemed probable that, by the aid of the adit, the basal beds of the Cambrian would be seen in direct contact with the underlying rocks.

Moel Tryfaen.

In the Geological-Survey maps the mountain of Moel Tryfaen is coloured as unaltered Cambrian on the east side, and as altered Cambrian on the west, the line of junction being marked by a great fault running from N.E. to S.W. The adit passes through the north side of the mountain from the Alexandra slate-quarries in the Cambrian beds on the east, through the altered beds, and then opens out on the west side.

The following were the beds seen from the opening inwards, as near as could be made out with the aid of the rather imperfect light at hand, some half dozen dip candles. At the entrance and for some distance inwards we found a greenish, sometimes pinkish or flesh-coloured, schistose rock containing disseminated quartz grains; further in, a more porphyritic-looking rock, mostly dark-coloured, with spots of highly vitreous quartz, in a base of felsitic matter, undoubtedly a greatly metamorphosed rock, and probably of ashy origin. About halfway in the tunnel we came upon some of the Lower Cambrian beds in an unaltered state, chiefly red and purple slates. About the junction of the Cambrian beds with the metamorphosed series there appeared to be several faults, which have undoubtedly reduced the thickness of the Cambrian rocks at this point, but have not altered the general order of succession. At the entrance of the adit to the quarry is a thick band of a chloritic and talcoid rock, one

* For the discussion on this paper, see p. 165.

of the hard bands frequently found interstratified between the slates, and which, in some cases, shows a semicrystalline texture.

The dip of the beds all along seemed to be nearly vertical, though the bedding could not be satisfactorily made out in the metamorphic rock. From evidence derived from other sections along the same line, we were inclined to think that the dip of the metamorphic beds was towards the N.W., whilst the dip in the Cambrian slates was to the S.E., and hence that the two series were discordant to one another.

The crest of the mountain consists of an unaltered conglomerate, in which the pebbles are for the most part made up of masses of quartz, quartz-felsites, porphyritic rocks, and schists, each appearing to resemble the rocks *in situ* near. The metamorphic rocks crop out immediately under the conglomerate on the mountain-side; and if our evidence of the dip in these metamorphic rocks is true, then they must be perfectly unconformable to the Cambrians above.

We did not succeed in touching the conglomerate in the tunnel; but Prof. Hughes informs me that he found masses of it in the débris at the mouth when the excavation of the central portion of the tunnel was carried on. All we can state in regard to the evidence at this point in the tunnel is, that we noticed a sudden transition from highly metamorphic rocks to unaltered Cambrian beds, the metamorphic rocks being, if possible, in a higher state of alteration near the junction than at a considerable distance deeper in the series, this probably being due to the presence of dykes of an intrusive rock which we found near.

The evidence at Moel Tryfaen is certainly most favourable to the view that the rocks coloured as altered Cambrian are entirely unconformable to the Cambrians which rest upon them, and that the metamorphic action does not extend beyond the line of the conglomerates, which here, as in all other Welsh areas, strongly define the base of the Cambrians.

Following the direction of strike of the conglomerates to the south-west of Moel Tryfaen, they may be traced to Mynydd y Cilgwyn; and there again they rest in an unaltered state on highly altered beds, similar in character to the metamorphic rocks on the west of Moel Tryfaen.

Pen-y-groes to Tal-y-sarn.

The evidence above given we were partly in expectation of finding from Prof. Hughes's statement, and from the colours on the Geological-Survey Map indicating an altered series. We also found, however, that the great patch coloured as intrusive porphyry to the west and south-west of these altered beds, and to contact with which it was supposed this change was due, consists also almost entirely of similar rocks to those above described, and moreover that the great mass is really made up almost entirely of schistose rocks, breccias, and other altered beds. The general character of the rocks in crossing from Pen-y-groes on the west side to Tal-y-sarn on the east may be described as follows:—About Pen-y-groes felstones and quartz-felsites, of either a dark bluish or a pinkish tint predominate; a little further east some highly siliceous-looking rocks, in which are disseminated throughout minute grains of quartz, with spots also of highly vitreous quartz. We found in these last rocks tolerably good indications of lamination and bedding; and they are undoubtedly made up of ashy materials subsequently altered, now a kind of quartz-felsite breccia*.

In another road-side quarry, a little further on, the rocks assumed a more schistose nature, but were otherwise much like the former. The bedding here was clearly seen; and the strike of the beds was apparently from N.E. to S.W., dipping to the N.W. at an angle of from 75° to 80°.

This quarry would seem to be as near as possible about the centre of the great mass coloured as intrusive felspar trap and quartz-porphyry. The same general characters seemed to prevail all along to the fault on the east of the village of Tal-y-sarn. In the village itself we came on to a dyke of truly intrusive porphyry, of a character very unlike any we had previously met with in crossing the great felsitic series.

This, according to Mr. Hudleston, is an undoubted greenstone porphyry, with large crystals of felspar in a dark-green subcrystalline base, containing also some hornblende and felspar disseminated, and a good deal of epidotic (?) matter. This appeared to have been intruded nearly at the junction of the Cambrians with the metamorphic series.

The dyke itself is probably altogether in the Cambrian rocks; and some slight alterations visible in the Cambrian rocks near here and at some other points must be attributed to contact with or proximity to one or more of these dykes.

On the above evidence we feel justified in placing the so-called altered Cambrian of Moel Tryfaen and neighbourhood, and the whole of the rocks in the large area coloured as intrusive felstone and porphyry to the west and south-west of Moel Tryfaen and Tal-y-sarn (excluding only some more recently intruded dykes), with the Pre-Cambrian rocks; and we shall moreover endeavour to show by lithological evidence to which group in the Pre-Cambrian rocks they appear to belong. Before doing so, however, it will be necessary to see whether the characters made out to be typical of this district are continuous in the area similarly coloured to the north-east, towards and beyond Llyn Padarn, west of Llanberis.

Llyn Padarn.

As anticipated, we found that the rocks similarly coloured with those to the west of Tal-y-sarn and Moel Tryfaen, along the north and south shores of Llyn Padarn, were for the most part identical in character with them, though, on the whole, rather more highly porphyritic. As numerous dykes of greenstone and melaphyre seemed to have been intruded into the series here, it is possible that

* See Mr. Davies's Note appended.

this higher state of alteration may have been induced in them in consequence. It is more than probable also that we have in the series here some contemporaneous lavas, and that the compact felstone weathering white on the surface so as to give a brecciated appearance, to be seen to the north-west of Llyn Padarn, is chiefly of this nature, though also in part a true breccia. The Cambrian conglomerates are frequently found resting on the central so-called porphyritic series along both sides; and the pebbles in the conglomerates are usually identical in character with the rocks below.

These are usually distinctly rounded, and generally imbedded in either an unaltered or a semicrystalline matrix, from which they can be easily removed. They were evidently in their present state, as regards consolidation, before they were cemented together to form the conglomerate, and must have been derived from rocks already highly metamorphosed at that time—such rocks, indeed, as now occur immediately under them, and which, we venture to believe, belong to a Pre-Cambrian series.

Sometimes these conglomerates strike up against the central series; but when this occurs it is found that they are brought into that position by faults, the far more usual positions being the flanking of the series on both sides.

It has been supposed by Prof. Ramsay and others that these conglomerates, especially at the eastern edge of the porphyritic series on the south of Llyn Padarn, are altered by and actually pass into the so-called porphyry.

The following description from Prof. Ramsay's memoir on North Wales will explain his view:—" So closely does the matrix of the altered rocks resemble the adjoining typical porphyry in colour, texture, and even in porphyritic character, and by such insensible gradations do they melt into each other, that the suspicion or, rather, the conviction constantly recurs to the mind that the solid porphyry itself is nothing but the result of the alteration of the stratified masses carried a stage further into the region of that kind of absolute fusion that in so many regions resulted in the formation of granites, syenites and other rocks, commonly called intrusive." This alteration, he believes, took place towards the close of the Silurian period.

The view held by Prof. Ramsay is also, I find, supported by Mr. G. Maw, in his paper in the Geological Magazine, vol. v. No. 3; and the unconformity supposed by him to be present here is placed considerably higher in the series than the conglomerates. The true reading of this section, to our minds, will not admit of an unconformity at the point mentioned by Mr. Maw, but it must be sought for at the junction of the conglomerates with the metamorphic series below, as at Moel Tryfaen and other places in North Wales.

The curious change in the rocks which he has taken for an unconformity is probably, as suggested by Prof. Hughes, only an appearance due to rock-structure, not uncommon in beds of unequal texture and extent, cleaved so as to crumple the hard beds and thrust the cleaved slates into the folds. Similar appearances have been observed in other slate-quarries in these areas also where rocks of unequal texture have been folded together.

It is perfectly clear, after the evidence derived from the Moel-Tryfaen area, combined with that obtained in South Wales, that the interpretation given by Prof. Ramsay, Prof. Sedgwick, and others as to the intrusive characters of these porphyritic ribs is not satisfactory, according to recent knowledge, and that it cannot properly explain the age and succession of these beds.

I believe there can be no doubt now that the Lower Cambrian series, as far as they are anywhere known in Wales, exhibit their proper thickness, and show their usual successive changes in character, when not affected by faults, and comparatively in an unaltered state all along this great axis of metamorphic rocks in Caernarvonshire—and that the conglomerates at the base rest upon beds of this axis, which are now in much the same condition as they were before any of these Cambrian sediments were deposited upon them.

The supposed intrusive nature of these ribs, and the apparent passage by gradual alteration mentioned by various observers, are mainly due to the fact that the matrix in the conglomerates has been derived from rocks immediately below or from similar ones, and from a slight subsequent change in the matrix, due, probably, to proximity to the intrusive dykes, aided by a readiness perhaps in the material to assume this change. This is clearly observed by watching the weathering of these conglomerates even when in direct contact with the porphyritic series; for any apparent melting-away of the hard pebble is shown not to be a fact, since on very slight weathering the pebble becomes easily separable from the matrix, and its outline is as perfect as on the day it became cemented in the mass.

This appearance as if of a gradual passage from conglomerates to rocks below, and from which most of their materials must have been derived, has often presented itself to my mind in examining these basal lines of the Pre-Cambrian rocks; but a careful and minute examination of the matrix and pebbles has invariably shown that such was not really the case. It must not be forgotten also that in speaking generally of the Cambrian rocks as an unaltered series, it is only meant that they are comparatively so when in juxtaposition with a true metamorphic series, such as we invariably find the Dimetian and Pebidian rocks to be. The Cambrian rocks themselves suffered some change before consolidation; and cleavage would have taken place in them; and a state of semicrystallization is also observable occasionally in some of the hard gritty bands, especially those associated with the lower slate beds, such as the one mentioned in the Alexandra quarry &c. This great mass or, as I would now say, great area of Pre-Cambrian rocks extending through the heart of Caernarvonshire from below Tal-y-sarn on the south to St. Anne's chapel near Bethesda on the north, along with another area near Caernarvon and Bangor described by Prof. Hughes, are undoubtedly portions still remaining of the old Pre-Cambrian land; and in them, I believe, are to be recognized representatives of the two great unconformable series, Dimetian and Pebidian, so well shown at St. David's. With the former of these I would associate the so-called syenitic ridge (granitoid rock) at Caernarvon; and with the latter the altered beds which rest directly on the syenitic ridge towards Bangor, and the series chiefly described in this paper to the south and north of Llyn Padarn and Moel Tryfaen. The prevailing characters in this last series indicate the metamorphism of a Pre-Cambrian volcanic group of ashes and breccias rather than of true sedimentary beds, the result of denudation and alteration only; and this, as is shown more fully in the following paper *, is also the character of the larger part of the Pebidian group at St. David's.

This proof of the extension of Pre-Cambrian rocks into and under the North Welsh area is highly interesting, and likely, I hope, to lead to researches in other areas where the Lower Cambrian rocks are exposed. The rough materials of which the Lower Cambrian rocks are for the most part made up indicate the presence of land near at hand when they were deposited; and the almost invariable difference to be observed in these formations, when seen on a large scale, in the one being a highly metamorphosed series and the other but slightly changed, ought greatly to aid in this research.

Note on a Rock-specimen *from the* Centre *of the so-called* Porphyritic Mass *to the* East *of* Tal-y-sarn. By T. Davies, Esq., F.G.S.

A microscopical examination of this rock discloses a very fine-grained ground-mass containing evenly distributed quartz grains, and a felspar in very small, dull, opaque, crystalline grains.

In thin sections, under the microscope, the quartz is found to be more abundant than at first was evident; indeed it forms a very considerable part of the mass. It is very angular in outline, and appears to be fragmentary, the rounded crystalline grains with inclusions of the ground-mass, so characteristic of the quartz-felsites and porphyries, being but sparsely represented. The felsitic ground-mass is very uneven in texture, has very little action on polarized light, and is only occasionally to be observed folding in bands around a crystal of felspar or quartz. In some parts the quartz grains are so numerous and closely aggregated as to afford but little space for the ground-mass, and bear a close resemblance to some of the more quartzose members of the so called "ashes" of North Wales. The felspar, like the quartz, is very fragmentary and much kaolinized. Some altered magnetite is present.

The rock is evidently a breccia in which both the fragments and the cement are of the same mineral nature; it is, in fact, a quartz-felsite breccia.

* This paper, with the title "Additional Notes on the Dimetian and Pebidian Rocks of St. David's," will appear in the next Number of the Journal.

14. *Additional Notes on the* Dimetian *and* Pebidian Rocks *of* Pembrokeshire. By Henry Hicks, Esq., F.G.S. *With an Appendix by* T. Davies, Esq., F.G.S. (Read December 5, 1877.)

In my former paper on the Pre-Cambrian rocks of St. David's (Quart. Journal Geological Soc. vol. xxxiii. p. 229), I was able to give a tolerably full description of the rocks which formed the central ridge, or axis, of the promontory; but of those in some of the other areas the descriptions, from want of sufficient time for the examination, were necessarily imperfect. Another three weeks spent last summer in further researches in these areas, enabled me to note many additional facts in regard to their distribution and mineral characters, which I hope may be of some interest and use to the Fellows of the Society. These results also greatly add to the completeness of the descriptions already given, and render an attempt at a correlation with other districts, I think, possible.

Dimetian.

The additions made to our knowledge of these rocks go to show their extension into the area between Brawdy and Hayscastle, ten or twelve miles to the east of St. David's. They form an axis to the newer rocks in that neighbourhood similar in many respects to the one at St. David's; and they are there flanked in part by metamorphic Pebidian, and along both sides by unaltered Cambrian rocks. This portion of the country is so much covered over by drift that it is difficult to meet with many good sections. But whenever these rocks (coloured as granite in the Survey Maps) are exposed they are generally like in character to those forming the central axis at St. David's, especially to the more highly altered or granitoid parts of the series.

About Brawdy and Asheston the rock weathers readily into a rough granular material with a yellowish staining, similar to that which occurs in beds of the other axis in a quarry at Porthclais and under the Camp, both in the valley south of St. David's.

The following appear to be the chief rocks which make up the Dimetian series, as exposed in one or other of these neighbourhoods; and added are some of the chief localities where they may be examined. For ready reference I will describe them as they may be traced from the fault about a mile north of St. David's to the coast, about three miles to the south-west.

1. Quartz porphyries, containing frequently perfect quartz crystals (double pyramids), subangular masses of quartz, and crystals of felspar in a matrix of greyish or greenish felspathic material (*vide* Appendix, § 1). They seem to extend right across the ridge from west to east at this point, and they therefore form a good base for our section. They are possibly intrusive, though appearing distinctly to

lie in the line of the bedding of their associated quartz rocks. As changes of equal extent, however, have been recognized as due to metamorphism in such rocks in other areas, I venture to retain them for the present as a special group in the Dimetian series with a probably volcanic origin. Prof. Bonney tells me he considers them to be most like a lava flow. Localities: Quarries north of the Church Schools, St. David's; and Caerbwdy valley, between Trefynard and Trepuet, &c.

2. Fine-grained quartz-felsites, very compact and usually of a greenish-grey colour and containing specks of viridite (Appendix, § 2). They are frequently associated with the above-mentioned rocks (No. 1), and interbedded with them. They also extend further south, and may be met with in numerous exposures along the side of the hill to the east of the Cathedral. They were also the chief rocks passed through in digging a well, 40 feet deep, at Glasfryn, near the centre of the ridge east of St. David's, a few years since, but interstratified here with beds of the next series.

3. Ashy shale-like rocks of a dull green or bluish colour, sometimes highly indurated, but usually showing lines of lamination. They are chiefly associated with the beds No. 2 and the next series; and they may be seen in one of the paths in the church-yard east of the Cathedral, in some road exposures along Goat Street, and in a quarry on the west side of the St.-David's valley south of the camp. This quarry is about half a mile south of the Cathedral, and is well worth examining. These rocks have also generally been met with in digging most of the wells at St.-David's; and the chief springs usually occur in them. On microscopical examination these bands prove to be all altered basaltic rocks (see Appendix, § 3).

4. Compact granitic-looking (granitoid) rocks, usually of a light green, or grey tint, but with sometimes a pinkish hue. The quartz is only partly crystallized, quartz grains occurring usually in abundance, and making up in most cases by far the largest proportion of the mass. The felspar is chiefly orthoclase; and there is also a green mineral, occasionally in considerable quantity. (See Appendix, § 4, and also note at foot by Prof. Bonney.)

These rocks attain a great thickness, and extend all along from directly south of the city to Porthclaish Harbour, and may be examined in numerous exposures along both sides of the valley; they are interstratified, however, with a few bands of the green ashy shales, also by quartziferous breccias.

5. Quartziferous breccias, consisting chiefly of angular and rounded bits of quartz and fragments of rocks like No. 3. (Appendix, § 5.)

6. Quartz schists (granitoid rocks) of a greenish and pinkish tint, containing frequently some dolomitic and chloritic materials. (See Mr. Davies's notes in my former paper, Q. J. G. S. vol. xxxiii. p. 231.)

7. Quartzites, usually of a slightly greenish tint, from a small admixture of a chloritic mineral *.

* The series 4, 5, 6, 7, make up the bulk of the Dimetian, and collectively show that the thickness claimed by me for this formation in my former paper, viz. 15,000 feet, is not an overestimate. The beds strike everywhere across

8. Purplish and greenish chloritic-looking bands with a schistose or rude cleavage structure, all apparently, on microscopical examination, highly altered basaltic rocks.

9. The crystalline limestone bands described in our former paper.

Nos. 5, 6, 7, and 8 are best seen in the coast section along the east side of Porthlisky Harbour, where they may be examined alternating with one another, but not exactly in the above order.

Intruded amongst all these various series are to be found occasionally dykes of greenstone, porphyry, and dolerite.

The indurated ashy shales showing frequently distinct lines of lamination and the so-called chloritic schists, mentioned in the above series, ever since 1864, when Mr. Salter and I first noticed their persistent strike in one direction over a large area, have continually caused doubts to be raised in our minds as to their true nature and origin.

In 1865 I forwarded notes to Mr. Salter, in which I mentioned facts to show that some at least of these were intrusive; and this caused him to communicate a note to the 'Geological Magazine' for September 1865, in which he states that I had proved that we were previously in error in supposing them to be truly interbedded, by finding portions of the schists entangled in the so-called Syenite. Subsequently examinations, however, seemed to show that there

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the ridge and at a very high angle; hence a great thickness is traversed in crossing the section from St. David's to the extreme point in St. Bride's Bay, beyond Porthlisky. At Porthlisky Harbour the beds are probably repeated by folds; otherwise the changing characters noticed in the sediments indicate that we have on the whole a continuously ascending series. It is satisfactory to note also that the further critical examinations which have been made of the rock-specimens go to confirm the opinions I previously expressed concerning the sedimentary origin of the majority of the rocks in this formation; whilst, on the other hand, some doubts have been cleared up, especially as to the true nature of the interstratified dark bands, which are of considerable importance. I have great pleasure in adding the following Notes by Prof. Bonney, M.A., F.G.S. (made on a separate set of slides), as it will be seen that they are entirely confirmatory of the observations previously made by Mr. T. Davies, F.G.S., and myself:—

Granitoid Rock, Dimetian (No. 4). "I have no doubt this is an altered rock *not* of igneous origin. It seems, however, much altered, like many specimens of gneiss. It contains much quartz, a fair amount of felspar, in which I recognize both orthoclase and plagioclase, and a little viridite, probably replacing a black mica. Here and there I note an approach to a graphic structure."

Quartziferous Breccias, Dimetian (No. 5). "A rock of distinctly clastic origin, containing fragments of quartz and felspar, variable in size, generally angular and subangular. There is also a little of a green mineral probably allied to chlorite. I recognize some plagioclase among the felspar. I see nothing to suggest a pyroclastic origin; but it appears to be the kind of rock which might come from the denudation of a gneiss or granite where the materials had not been transported very far, a sort of 'arkose.' It looks to me as if it had been rather crushed since solidification."

Quartz Schists, Dimetian (No. 6). "These are difficult and interesting rocks. They consist mainly of quartz and felspar with a little viridite, the former, perhaps, rather predominating. In parts they exhibit a sort of graphic structure; still I regard them as altered rocks and belonging to the same group as No. 4. There is rather too much felspar for a normal quartzite."

were two distinct series of these green bands:—one undoubtedly occurring as intrusive dykes, showing also a columnar structure; the others running everywhere parallel to one another, and apparently interbedded with the quartz rocks. In my last paper (Quart. Journ. Geol. Soc. vol. xxxiii. p. 229) I kept to this view, and continued to consider these as marked distinctions and as probably indicating a different origin for the two series. It seems now, however, tolerably clear from the examination of specimens of rocks from each series kindly made for me by Prof. Judd, F.R.S., and Mr. T. Davies, F.G.S., that the interbedded masses are microscopically almost identical in character with those which appear as dykes, and hence that both series are probably of igneous origin. Of one of these bands Mr. Davies gives the following description:—"This is a highly altered basic rock, completely chloritized, only the felspar being indicated by its outline. The ground-mass is pervaded with chlorite, while fissures containing the mineral and much calcite traverse it in all directions."

The following descriptions of specimens from different bands by Prof. Judd are also interesting.

a. This rock is so similar in character to that which occurs in dykes, that I can find no characters by which to separate it. Only the outlines of the original constituents can be traced, it is true; but the whole aspect and mode of arrangement is so similar to that of the dolerites, that, unless the geognostic evidence be of the most unmistakable character, it would be well to pause before calling it a metamorphic rock.

b. More nearly resembles a metamorphic rock than either of the others; but it presents no characters which would warrant one in asserting that it was not a greatly altered igneous rock.

c. In spite of the parallel arrangement of the crystals in this rock, I cannot think that it is a metamorphic sedimentary rock.

The quartziferous breccias described by us in a former paper* are found at several horizons interstratified with the more compact quartz rocks. These may possibly be volcanic breccias, but are most probably, I think, compact quartz breccias entirely the result of denudation, and in which the matrix rather readily decomposes by atmospheric action; they invariably have a strike of about N.W. to S.E., and hence, across the ridge and parallel to the strike, in the compact quartz rocks under St. David's, and the quartz schists at Porthlisky. One thick band of these brecciated-looking rocks may be seen cropping up at Lower Moor to the south of St. David's; and another is exposed in the valley still further south on the hillside near the road leading to Porthclais.

Pebidian.

In my former paper I was able only to describe the Pebidian rocks which immediately flanked the Dimetian axis, and had to

* Quart. Journ. Geol. Soc. vol. xxvii. p. 387.

pass over other and larger areas with simply mentioning their presence there. This was particularly the case with the area to the west of the St.-David's axis, which I propose more especially to refer to now.

This area also reaches beyond the point indicated in my former map, and may roughly be made to include all the so-called altered Cambrian beds and most of the intruded masses associated with them within a line marked as running from the S.W. point in Ramsey Sound, by Rhosson, to the south-east corner in Whitesand Bay, called Ogof Golchfa, and bounded beyond by the great fault running in a N.E. direction from that point to Tretio, at which place they are dropped by the fault extending here from east to west. This area is in length about seven miles, and it has an average width of about a mile and a half: nearly all the beds contained in it are higher in the succession than those mentioned as immediately flanking the Dimetian axis in my former paper; and hence they will now require a special description.

As, however, the lowest beds of the Pebidian are nowhere well shown in this area, and in the line of the section across it (which I propose to describe) they have been cut off by the fault marked as occurring at the junction of the Pebidian with the Dimetian, I must refer to these again and describe them as they occur on the east side of the axis, especially as several additional facts of interest have been observed in regard to their lithological characters, &c.

In Section II. (fig. 2, p. 166), which is in reality but a continuation towards the south-east of Section I., the Pebidian rocks, are observed to lie unconformably upon the Dimetian axis. The lowest beds as (1) seen on the hillside and in the valley (Caerbwdy), where the road from St. David's to Solva crosses it, are made up of an agglomerate in which large masses of a spherulitic felstone lava, angular pieces of green shale, bits of chloritic schist and quartz rock are imbedded in a sea-green felsitic matrix, studded with smaller fragments of similar rocks, and broken and sometimes perfect crystals of felspar (*vide* Appendix, § 1).

(2) Conglomerates of the same materials as No. 1.

(3) Light-green thin-bedded banded shales, usually highly indurated, or porcellanitic in character, with a conchoidal fracture.

(4) This series is for the most part hidden by the Cambrian conglomerates, which overlap it on this side of the axis. In some places also it is cut off by faults.

In Section I. (fig. 1) a few of the beds of this series (No. 4) are seen directly beyond the fault in the hill on the east side of the St.-David's valley to the north of the Cathedral. They consist for the most part of greenish and purplish felspathic breccias, weathering white on the surface, but often stained of a yellowish-red colour from the iron contained in them. These rocks readily decompose on exposure, and are much used in road-making for binding the rougher road-materials.

(5) Alternations of silvery-white schists, purple shales, and light-

green clay slates, often spotted. These are chiefly seen on the east side of the St.-David's valley going northwards. These and the underlying breccias dip away from the Dimetian axis at a high angle, usually about N.N.W.

(6) A series of greenish, reddish and purplish indurated ashes and ashy shales. The rougher ashes are frequently conglomeratic, and sometimes contain pebbles of considerable size, the masses being chiefly purple and green shales, felstone, and quartz. The matrix is studded throughout with an abundance of dull and glassy quartz grains and with broken bits of felspar. In the finer ashes, which are sometimes highly indurated, these quartz grains give the mass quite a porphyritic appearance; and it is impossible not to be impressed, when looking at some of these beds, with the opinion that, had metamorphism been carried a little further here, the result would have been, to all appearance at least, a tolerably good quartz porphyry.

The beds of this series attain a considerable thickness, and may be traced all along the west side of the valley, from a quarter of a mile above the Cathedral to half a mile below near to the Camp, and then across in some road exposures to Clegyr-foia rock. This last rock, which stands out alone considerably above the general surface, consists chiefly of bands of highly indurated fine-grained green ash (Appendix, § 2), which does not weather readily, interstratified with softer reddish and purplish shales.

(7) In the marshy ground beyond Clegyr-foia, the rocks are almost entirely hidden by a considerable thickness of marly clay, the result probably of the gradual decomposition of the underlying rocks, combined with an admixture of a certain amount of surface-drift. There are, however, one or two exposures just at entering the moor, which show that the underlying rocks are a continuation, as would be expected by the line of strike, of rocks exhibited in a cliff-section at Porthlisky Harbour to the south of this point. At the latter place they have been brought by a fault to rest directly on the Dimetian axis, but dipping away from it at a very high angle. They consist for the most part of reddish, yellowish, and whitish schists and slates, alternating with beds of volcanic tuff. In some cases they are hard and gneissoid in character, but mostly soft, and decomposing readily on exposure to atmospheric influences.

(8) On the west side of the harbour the last-mentioned series is followed at a rather low angle of dip (the effect doubtless of a fault) by conglomerates and ashy beds. The ash-beds and the conglomerates are much like those described as occurring on the west side of the St.-David's valley, the matrix being also like in containing an abundance of quartz grains, sometimes of large size.

There are also some bands of a reddish ash rather prettily blotched with green and white, the latter being bits of felspar in a state of decomposition.

(9) A thick band of felstone weathering white, with a brecciated appearance on the exposed surface, but rather compact internally; this seems to be a true interbedded lava of contemporaneous origin.

At Ramsey Island, associated with a similar lava, there occurs a good breccia in which large masses of hornstone occur imbedded in a felstone matrix, studded with grains of glassy quartz. Here also are seen some bands which appear to be good quartz felsites.

(10) Succeeding the felstone in the section occurs another series of hard bright-green ash bands, and a rough ash with fragments of a very dark green rock. In this series Mr. Hudleston noticed a good vein of epidote. These beds, as well as some in the other series, are frequently traversed by thick veins of quartz; and it was associated with one of these that the epidote was found. Veins of asbestus also have been observed in these rocks.

(11) The last series exposed in this section is made up of reddish and purplish ashy schists. They are not exposed immediately in the line of the section, but are found on the coast of Ramsey Sound to the south, and at Whitesand Bay, on the east side, to the north. They are seen at the last place to be covered unconformably by the Cambrian conglomerates, and are here penetrated by a thick trap dyke, which is also overlapped by the conglomerates.

The line of strike of the Cambrian rocks appears at first sight to be nearly identical with that of the underlying Pebidian beds; but when examined carefully it will be seen that in no case is it truly so, but that the conglomerates overlap the beds irregularly and at different points in the succession. They usually dip also at a lower angle than the Pebidian beds. Moreover the latter are always more or less highly metamorphosed; and the Cambrian conglomerates are largely made up of pebbles derived from these rocks in their altered state, imbedded in an unaltered matrix.

The thickness of the Pebidian rocks as exposed at St. David's may be estimated now at least at 8000 feet.

In my former paper I only gave it at about 3000 feet, as I was then doubtful whether the series to the west was a continuous one, or whether it simply consisted of repetitions in folds of the beds immediately flanking the ridge. Now, however, it is clear from special characters indicated at various points in the section that it may be looked upon generally as a continuous series, possibly repeated partially by slight folds and faults, but yet sufficiently continuous to give at least the thickness I have now estimated it at. Throughout the whole series the bedding is very distinct, and generally at a high angle. As the beds also are overlapped by the Cambrians wherever the latter are not cut off by faults, this estimate may not approach to any thing like the actual thickness of the series if wholly exposed; but it is that which we may fairly claim for it as seen at St. David's.

In the other areas these rocks show some slight differences in their composition, and may possibly belong to higher positions in the group. The detached mass in Ramsey Island consists chiefly of felstone, felstone porphyry, and hornstone and felstone breccias. The Cambrian conglomerates resting upon this mass are also chiefly made up of rounded felstone pebbles, indicating that they were mainly derived from such underlying rocks; they are actually the beach-pebbles on an old coast line, the cliffs of which these rocks once formed, before they were submerged to receive the succeeding Cambrian sediments.

In Section III. (fig. 3) another patch of these Pebidian rocks is seen. This is on the coast near Newgale, about eight miles east of St. David's. The beds here, as in the other areas, are nearly vertical, and are chiefly felstones of a flesh-colour, with specks of hornblende. These are again flanked by Cambrian conglomerates containing pebbles identical with the rocks below. To the north-east of this mass is seen the second Dimetian axis, which extends for about six miles in an E.N.E. direction.

Between this axis and the one at St. David's a broken succession in several anticlinals and synclinals of Cambrian rocks is found, the highest being Tremadoc rocks in a synclinal curve near the centre, the lateral extensions of the older rocks forming therefore a kind of basin into which these have been compsedres.

From the foregoing descriptions it will be gathered that a very large proportion at least of the Pebidian rocks must have had a volcanic origin. As, however, they were at first subaërial and afterwards submarine accumulations, it is evident that they must also be partly detrital. The lowest rocks are the agglomerates; and in these I think we have clear evidence of proximity to a subaërial volcano surrounded by the ordinary materials of a volcanic cone, the largest proportion of the masses being fragments of lava which evidently had cooled under atmospheric influences. Again, associated with these fragments we find angular bits of chloritic schists, ashy shales, and quartzites, similar in every respect to beds now visible in the Dimetian series below. These bits may have been broken off in the eruption, or they may be fragments caught up by the cementing lava as it flowed over the land. The next sediments indicate the undoubted submergence of the area, as the masses are partially rounded and stratification is visible. These are followed by beds of fine sediments, and subsequently by a series of well-bedded ashes and lavas, which had evidently been cast out in a sea over a gradually subsiding area. The general likeness in the whole series to groups of volcanic rocks found in more recent strata is most marked, especially to those associated with the Lower Silurian in many areas; and, with the exception perhaps of a higher stage of metamorphism, there would be but little to guide one to an understanding of their age, if exposed in areas where the succeeding sediments had been removed. This may be one of the reasons why these rocks have not been more frequently recognized hitherto, especially as, until very recently, we were unaware of the occurrence of volcanic rocks of such great antiquity which retained any thing like so marked a character as these rocks have done*.

* It is an interesting fact, and one likely to prove useful as a future means for the correlation of these rocks with those in other areas, that similar changes seem to have taken place over considerable portions of the northern hemisphere, especially those bordering the Atlantic, at this epoch in geological time. According to the descriptions by Mr. Matthew, Quart. Journ. Geol. Soc. vol.

Conclusions.

We are now, I think, in a position to attempt an inquiry into the probable physical conditions, locally at least, of these Pre-Cambrian epochs.

In the oldest formation, the Dimetian, we have not, unfortunately, at St. David's, a base to start from, since in no case probably have we reached the lowest beds. There are no true conglomerates in the whole series; and of the lowest beds, or those which seem to form the centre of an anticlinal, we are not sure whether they may not even be intrusive. The next beds in this group are a great series of altered quartz rocks and very fine-grained quartzites; but with these are associated a few of the ashy-looking bands mentioned as either intrusive along the bedding or contemporaneous basaltic flows. These beds alternate with one another, and hence appear as if contemporaneous. The prevalence of volcanic action at this time is therefore rendered more than probable. Still the enormous preponderance of quartz rocks throughout the whole formation, and the absence of ashy beds and of felstone lavas and volcanic breccias of any great importance, indicate to my mind that it was probably chiefly detrital in its origin, the result of the wearing-down of previously existing rocks. Whether this formation is chiefly made up of detrital or volcanic materials, however, is a question chiefly for the chemist and mineralogist.

The question which to us is now of importance is that of its position geologically; and upon this point I venture to speak with some confidence. The stratification shows undoubtedly that it is older than, and that it is overlain unconformably by, the Pebidian formation. Moreover, fragments of its several rocks are found in the beds of the Pebidian which rest immediately upon it; and hence it must have been in existence, either in the form of an island or as a portion of a continent, in pre-Pebidian times. It was through its consolidated rocks also that volcanoes burst forth; and upon them also was spread out the material which was afterwards depressed below and sorted and rolled by the encroaching Pebidian sea.

The depression of the land during the Pebidian epoch was undoubtedly accompanied throughout by volcanic action, chiefly submarine; and though we do not know to what thickness this series may have attained, nor, consequently, to what extent depression went on, we know that the close of the epoch was accompained by the re-elevation of the parts depressed, and by great changes over vast areas. The history of the changes which took place at this time we may partly read in the well-known Lower Cambrian rocks, the next series in order of deposition*; for, when their base-line is seen, they

xxi., Dr. Dawson, 'Acadian Geology,' and Prof. Nicholson, Quart. Journ. Geol. Soc. vol. xxix. p. 21, the Huronian Epoch in Canada and New Brunswick must also have been a period of volcanic activity, and the rocks are to a great extent similar in character to those of the Pebidian formation on this side.

* See papers by the author, Quart. Journ. Geol. Soc. vol. xxxi., and Geol. Mag. April 1876.

invariably show massive conglomerates of well-rolled pebbles indicating the prevalence of beach-conditions over those areas, either as shore-lines to islands in shallow water, or coast-lines of an uneven land which was once more becoming depressed below an encroaching sea. The pebbles, as already shown, also almost invariably for the most part consist of fragments of the rocks upon which they lie; and when examined they tell distinctly that the underlying Pebidian rocks, after they were elevated, when these fragments were broken off, and before they were again depressed, were not only consolidated, but also nearly as highly metamorphosed as they are found to be at present.

The changes referred to may be briefly summarized as under:—

Dimetian.

1. Depression of pre-Dimetian land.
2. Deposition of the sediments, accompanied by some volcanic action.
3. Elevation, accompanied by consolidation.
4. Land areas with volcanoes.

Pebidian.

5. Depression of the land.
6. Deposition of loose materials washed off from the Dimetian land with gradual submergence.
7. Heaping-up of materials chiefly derived from submarine volcanoes, accompanied with moderately rapid depression.
8. Re-elevation of the areas depressed, probably to a considerable height, with consolidation of the rocks. This change, which produced the immediately pre-Cambrian land, was undoubtedly accompanied in places by considerable fractures in the previously consolidated Dimetian rocks, as the Pebidian beds are seen to lie across the edges of these rocks and in positions which I think they could not have assumed after perfect consolidation in themselves.

The great faults, however, which are met with in these areas were undoubtedly produced at a much later period, probably about the close of the Palæozoic, and were doubtless due in a measure to the indurated state at the time of these two early formations, and to their readiness therefore to fracture rather than to bend in the great movements which took place in the crust of the earth at the close of Palæozoic time, when the Cambrian and succeeding sediments were readily bent into folds.

Note (March 18, 1878).—There can be no doubt in the mind of any one who carefully examines the various sections of these rocks at St. David's, that there must be here at least the representatives of two very distinct formations, evidently deposited under different physical conditions, and hence unlike lithologically. That they are unconformable to one another also seems beyond doubt; for by no other means could they, as they do at all points, show a persistently opposing strike and become transgressive in the manner already indicated. In my other paper (*ante* p. 147) I show that the evidence points to their holding similar positions to one another also in parts of Caernarvonshire. Neither of these formations, so far as they are at present known, can be closely allied, petrologically, to the so-called Laurentian gneiss (Lewisian of Murchison) of the Western Highlands and Hebrides, or even perhaps to that in Anglesey and South-west Caernarvonshire; hence it seems more than probable that the latter belongs to a still older formation. They will, however, I believe, be found to have a wide distribution over the British area when the metamorphic rocks of the various districts have been carefully worked out; and even now evidence is gradually accumulating which points unmistakably to other areas than those above mentioned, such as Charnwood, the Wrekin, &c.* At present the indications, therefore, are that we have three British pre-Cambrian formations with rather marked petrological characters; and they probably occur in the following descending order:—

CAMBRIAN,

Sediments the result of denudation chiefly.

I. PEBIDIAN (Huronian? of Canada).

Deposits chiefly derived from subaërial and submarine volcanoes.

II. DIMETIAN (Upper Laurentian? of Canada).

Sediments chiefly the results of denudation, but partially volcanic.

III. LEWISIAN (Lower Laurentian? of Canada).

Deposits largely the results of denudation, but probably in part organic.

It would undoubtedly be unsafe to lay down a rule that formations may generally be recognized, and hence correlated, by petrological characters only; and yet there can be no doubt that most formations or groups of rocks show some peculiarities dependent on age and special physical changes at the time of deposition, which may frequently act as guides to correlation over considerable areas. In these pre-Cambrian rocks we have a persistent metamorphism, *with no local cause to account for it*; it is also somewhat peculiar to itself, due probably to great and repeated changes, from an alternation frequently from deep depression with great superincumbent pressure, to elevation. The above guides, therefore, if kept in view, may at least aid in a recognition in other areas in the absence of the fossil evidence which at present is wanting.

* See descriptions of rocks in these districts by Allport, Quart. Journ. Geol. Soc. vol. xxxiii. p. 449; Callaway, Quart. Journ. Geol. Soc. vol. xxxiii. p. 652; and Hill and Bonney, Quart. Journ. Geol. Soc. vol. xxxiii. p. 754.

Appendix *on the* Microscopic Structure *of some* Dimetian *and* Pebidian Rocks *of* Pembrokeshire. By Thomas Davies, Esq., F.G.S.

Dimetian.

1. The rock from near the Church School is seen macroscopically to consist largely of quartz in individual crystalline grains, or in groups, thickly distributed through a porphyritic-felsite ground-mass. In fissures and nests in the mass of the rock much chlorite and also some epidote are present. Its affinity to the quartz porphyries is only apparent when examined in thin section under the microscope. Here the quartz is seen to be distinctly crystallized, with characteristically rounded edges, and also with inclusions of the ground-mass. The felspar crystals are numerous, and much altered though the indications of banding of a plagioclase felspar are not wanting.

The ground-mass is microcrystalline throughout, consisting of quite individualized grains of quartz and felspar, and in many parts presents a peculiar structure. Around the quartz and felspar crystals an incipient spherulitic arrangement has taken place, resembling to some extent that seen in some rhyolites; but here the radial texture is modified by a tendency to a dendritic or a branched structure, a peripheral outline being in all cases absent. This structure is also developed from numerous individual centres in the ground-mass, having no apparent nucleus; it bears no resemblance to the rhyolite of the breccia before described, though it is probably but a modified form of spherulitic structure. Much green chlorite and a black indefinable substance is dispersed through the ground-mass.

2. This fine-grained, chlorite-spotted rock presents in thin section a completely crystalline ground-mass of felspar and quartz grains, the latter being but in small proportion. The peculiar dendrito-spherulitic structure, shown in the rock from the Church School, is present here also, but is not so distinct. Crystals of quartz are entirely absent; and but a few crystals of felspar are developed. The green chloritic mineral and the black substance, as in the Church-School rock, are pretty evenly distributed.

3 *a*. The dense purplish-black rock in contact with the quartzose rock is seen in thin section to consist of very small crystals of a plagioclase felspar pervading a grey uncrystalline ground-mass, which is perfectly opaque between crossed Nicols. With polarized light very small grains of a strongly polarizing mineral are seen, but they are not sufficiently distinct to admit of determination as to whether they may be olivine or augite. The felspar crystals lie more or less parallel to the line of junction with the quartz rock; it is to be referred to the basalt group.

3 *b*. The altered igneous rock in contact with the quartz rock in this section much resembles that of the preceding, though it is not so dense, and the indications of the more abundant presence of

augite or olivine are more distinct; that it also belongs to the basalt group is without doubt.

4. Consists principally of quartz with some felsitic material. In thin section quartz is seen to be the prevailing mineral; it presents no traces of crystals, but exists only as a granular mass, the felsitic material, which is much decomposed, filling the interstices and spaces between the quartz grains. Occasionally, though rarely, a crystal may be observed in the felsitic substance presenting traces of the banding of a plagioclase; chlorite is present.

5. Is apparently a breccia, consists almost entirely of subangular and rounded grains of quartz with remains of felspar crystals. Some of the fragments are evidently derived from a rock like No. 4. The whole is cemented together by a dark grey material, appearing like dust under the microscope.

Pebidian.

1. The rock constituting the fragmentary part of the agglomerate appears to consists chiefly of a spherulitic felsite porphyry, frequently banded with alternately dark greenish-grey and light pinkish-grey bands. It presents a very fine-grained texture, with a dull hornstone-like fracture, and exhibits, microscopically, distributed crystals of felspar having a feeble lustre. It weathers cream-white, the spherulitic structure when present being then perfectly exhibited on the surface. On freshly fractured surfaces, however, it is not to be detected, even with the aid of a lens, and the very large spherules, so prominent in the weathered specimens, present but faint indications of their presence.

Seen in thin sections under the microscope, however, the structure is at once recognizable, the whole mass appearing to consist of spherules, frequently arranged in well-marked bands of varying dimensions, and also confusedly grouped without any apparent arrangement. Felspar crystals of apparently two kinds, orthoclase and a plagioclase, are porphyritically developed—the former indicated by its characteristic Carlsbad twins, and the latter by traces of its original fine striation, though both are much altered, probably by kaolinization. Quartz grains, or rather immature crystals, are present but not in quantity, and are characterized by the absence of glass inclusions, those of fluid being but sparingly contained in them.

Around these felspar and quartz crystals the bands of spherulites stream, meeting on both sides, and in some cases being developed upon the crystals themselves, forming a botryoidal crust. In the larger spherulites, crystals and groups of crystals of felspar are frequent. The small interspaces between the spherules are mostly filled with a granular dark opaque substance, quite undefinable even with high powers, while occasionally a micro-crystalline felsitic mass with minute grains of quartz is substituted. A bright-green chloritic mineral is also sometimes present, probably derived from grains or crystals of augite, the outlines of some crystals of which, though very ragged, are still very distinct. The dark-green wavy bands seen in hand specimens differ from the pinkish-grey only in containing a larger amount of these granular and chloritic materials. Where the spherulites are but indistinct or not at all developed the fluidal structure is still shown by the bands of the dark granular mineral, the whole of the ground-mass in that case being crystalline. Apatite needles also occur, but sparingly, and are restricted to the vicinity of the crystals of felspar.

Microlites, so characteristic of the younger rhyolites, do not appear to be present; otherwise the whole structure of the rock, in the fluidal arrangement of the spherules &c., is so like that of a rhyolite that it is difficult to believe that we have not before us one at least of the many interesting varieties afforded by this group. One may say with Zirkel, it is a rhyolite petrographically, but not geologically. How long such a distinction can be maintained after the investigations of Allport and others upon other palæozoic occurrences of this rock, it is difficult to say.

The cementing material of the agglomerate, as seen in the microscope, consists in the main of numerous broken crystals and angular fragments of felspar and quartz enclosed in a fine-grained ground-mass consisting largely of the dark opaque granular substance, with exceedingly minute grains of a depolarizing material not to be recognized; but, from its resemblance to the larger grains of undoubted felspar, it is presumably felsitic.

Another mass of the agglomerate consists of more or less subangular fragments of a dark basic lava, slightly amygdaloidal, and much altered; the felspar crystals are exceedingly slender and only occasionally afford evidence of their plagioclastic habit; the ground-mass is black and opaque. The walls of the cavities are lined with calcite; and the interior is filled with a light-green clear chlorite. The cementing material is only to be distinguished from the enclosed fragments by its lighter colour, abundance of epidote, and the presence of groups of crystals of augite.

2. A compact dark-green rock, with a somewhat fissile aspect. Very little positive results are obtained by microscopic examination. Scattered throughout a greenish-grey dust-like ground-mass without action on polarized light, are innumerable minute grains and small fragments of a tolerably clear crystalline mineral yielding bright colours between crossed Nicols, which recall to mind the augite seen in many extremely altered dolerites.

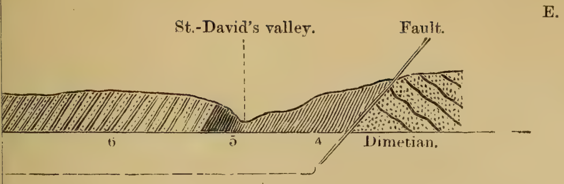
There are no visible traces of a felspar, while the whole mass is quite darkened with a granular nearly opaque substance quite undeterminable, and is much veined with a pale yellowish-green chloritic mineral. Can only be referred to the unsatisfactory group of altered volcanic ashes.

Discussion *.

The President remarked that these papers showed what important results may be brought about by persevering industry; it was by this that Mr. Hicks, Prof. Harkness, and others had gradually built up the system of the difficult and interesting country

* This discussion relates to the three preceding papers.

[*To face* p. 166.



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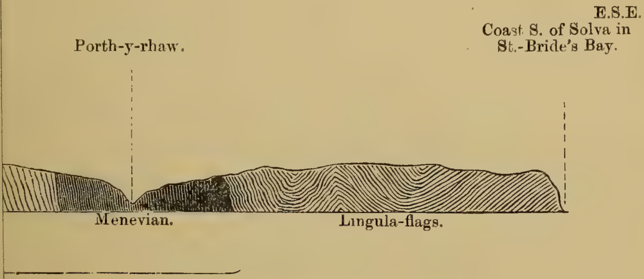
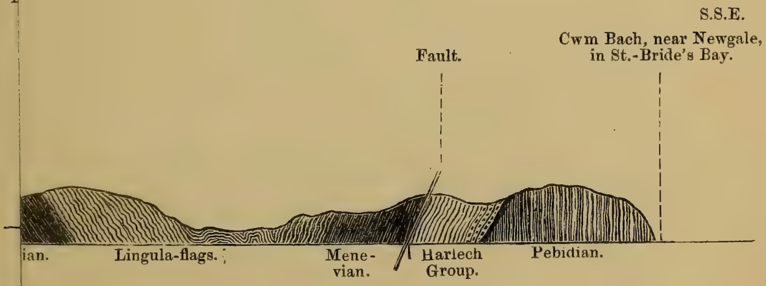




rates, breccias, and indurated ashy beds.

Fig. 1.—*Section from Ramsey Sound to St. David's.* (Length $2\frac{1}{4}$ miles.)

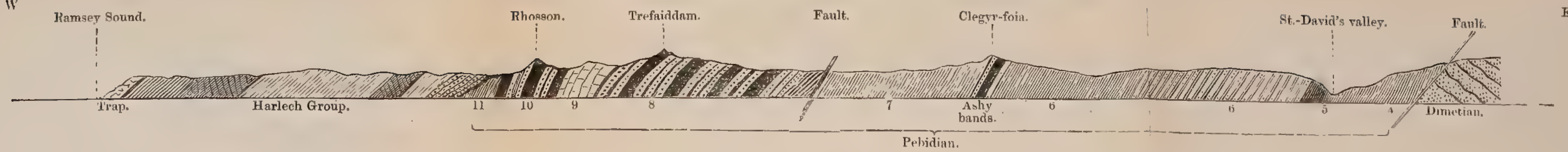


Fig. 2.—*Section from St. David's to the coast beyond Porth-y-rhaw.* (Length $2\frac{1}{2}$ miles.)

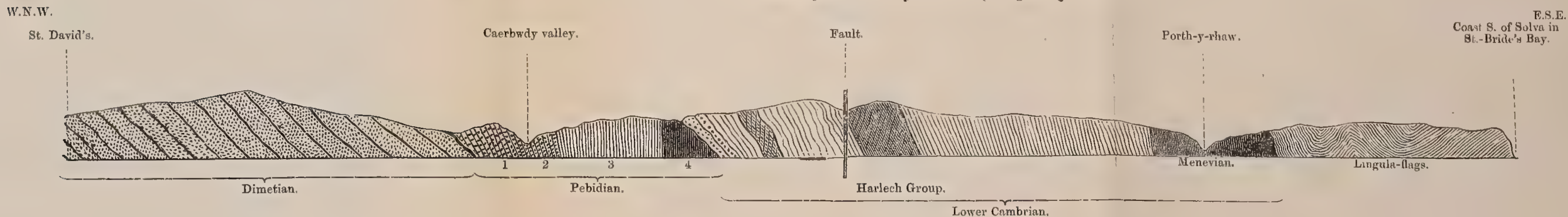
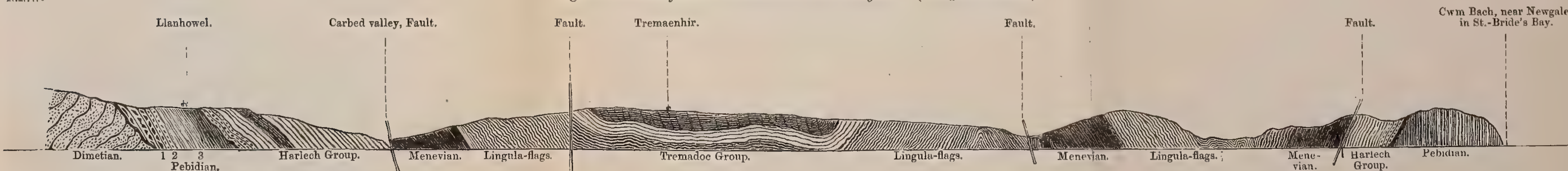


Fig. 3.—*Section from Llanhowel to near Newgale.* (Length 3 miles.)



The numbers indicating the subdivisions of the Pebidian correspond to those in the text (pp. 157–159):—

1. Agglomerates.
2. Conglomerates.
3. Porcellanitic beds.
4. Schistose beds and breccias.
5. Schists and slates.
6. Volcanic conglomerates, indurated ashes, breccias, and ashy shales.
7. Schists, tuffs, and indurated shales.
8. Volcanic conglomerates, breccias, and indurated ashy beds.
9. Felstone.
10. Ashy bands.
11. Schists.

to which the papers just read related. He said that, in considering the divergence of the opinions advocated by recent authors from those which had been long entertained, it must always be remembered that the later investigators possessed a means of research which was not at the command of their predecessors, the great progress of the study of petrology during the last few years furnishing them with a means of distinguishing and correlating these rocks comparable to that offered to the student of later sedimentary deposits by the fossils contained in them. He asked Mr. Hicks whether he could say any thing as to the age of the great crumplings and foldings described.

Mr. Tawney stated that there were porphyries near the fault taken as the base of the Dimetian by Mr. Hicks, which, as in the quarry below the Board-school, contain dihexahedral quartz &c., and are spherulitic ; again, near the Church-school, another coarser porphyry having much the aspect of ordinary Dimetian, but distinguished by large dihexahedral quartz, is also somewhat spherulitic, the radiating structure enveloping the quartz crystals. These porphyries are apparently eruptive, and seem to have produced contact-alteration ; for the Dimetian beneath them is dense and fine-grained, as if the constituents had been partially rearranged ; their nature, however, remains the same, not even the chloritoid mineral being absent. We may presume, then, that the Dimetian had assumed its crystalline character (metamorphic, Hicks) before the intrusion of the porphyries. Now, light is thrown on the age of the latter by the curious agglomerate above Clegyr bridge, which bed is placed by Mr. Hicks at the base of the Pebidian : fragments of analogous spherulitic rock enclosed therein have the same mineral composition, and are probably, roughly speaking, contemporaneous with the intrusive masses above-mentioned in the Dimetian. Hence, presuming the metamorphic origin of the Dimetian, we arrive at the later age of the Pebidian series, and its total unconformity to the Dimetian. Moreover the Dimetian is crystalline throughout, while the Pebidian contrasts strongly by its bedded shaly character.

Mr. Hudleston had travelled over the districts in company with Mr. Hicks and Prof. Hughes, and found that he had undertaken to furnish a short Appendix to Mr. Hicks's paper. Upon instituting a comparison between the St.-David's district and North Wales, the principal datum-line seems to be the great conglomerate taken as the base of the Cambrian, which may be deemed fairly synchronous in both areas. The point at issue was whether the beds *below* this, forming the subject of the present papers, were really pre-Cambrian, or had been metamorphosed and intruded at a subsequent period.

The contents of the conglomerate were very much in favour of the author's views.

Beginning now with a description of the lowest beds of the double series, there was considerable general resemblance between the highly crystalline and granitoid rock of Caernarvon and many of the Dimetians of St. David's, held by the authors to occupy an analogous position; but there was much greater complexity of character in the Dimetians, great masses of quartzy beds being mixed up with granitoid rocks and peculiar quartz-porphyries, such as that described by Mr. Tawney, the whole forming a crystalline acidic series, yet pervaded in many places by dark-green basic rocks, which, there is good reason to believe, are old dolerites. A very similar sort of rock occurs in the quartz-felsite mass of Llyn Padarn. The Pebidian rocks are more volcanic in their character, and, although in so large a series there must be great variety, the lower beds clearly contain abundant débris of acidic erupted rocks, such as the ancient rhyolite so well described by Mr. Davies. The quartz-felsites of Llyn Padarn, which are held by the authors to occupy an analogous position in the pre-Cambrian series of North Wales, fairly tally in petrological character, and may represent the acidic volcanic series of that area. The Upper Pebidian, however, as shown in the diagram, contains a group of rocks which have no representative elsewhere. The peculiar rock of Clegyr-foia may be taken as a type of these. They are in all probability bedded lavas and ashes of a basic character, which, on that account, have undergone more chemical alteration, and are well worthy of close study.

Taking all the facts into consideration, it is not unreasonable to suppose that in the more crystalline lower series, as developed near Caernarvon and St. Davids, we see the hypogene conditions of a great mass of rocks, whilst the beds between these crystalline masses and the great Cambrian conglomerate represent a more or less contemporaneous outpouring of lavas and ashes, partly subaerial, but, as regards the Pebidian especially, in a great measure remodelled and deposited by water.

Prof. Seeley remarked that as the whole argument rested on the examination of microscopic slides, upon which it was impossible to form a judgment from a hasty inspection, he did not see how the results arrived at by the authors could be satisfactorily discussed. He inquired, however, whether the succession of the beds as described by Mr. Hicks was such as to preclude those noted as lavas and ashes being really of metamorphic origin.

Mr. Drew said that even a cursory examination seemed to prove that some at least of the specimens were undoubtedly derived from ash-beds.

Mr. George Maw, in taking exception to the view expressed by Prof. Hughes, that the break he had pointed out in 1867 as included in the section near Llanberis, in the cutting of the Caernarvon and Llanberis Railway, was not due to unconformity, wished to know at which point below the horizon of this section Prof. Hughes had recognized unconformity between the Cambrian series and underlying porphyritic masses between Llanberis and Caernarvon.

Mr. Hicks said, in reply to Prof. Seeley, that there could be no doubt that a very large proportion of the Pebidian rocks were made up of volcanic materials stratified; but he quite believed that there was also a great amount of ordinary detrital sediment mixed up and interstratified with the volcanic materials, as evidenced by the presence of clay slate, hornstones, and porcellanites, &c.

In reply to the President's question, he said he believed all the great faults pointed out were of post-Carboniferous age, as they affected not only the Cambrian rocks, but also the Silurian, and in some cases brought Carboniferous beds to rest directly on Cambrian beds. Some of the other faults he believed were of much earlier date, possibly pre-Cambrian.

To Prof. Hughes, Mr. Hicks said he was sorry that they would have to disagree on one or two points. He sympathized with him in trying to claim all he could for his eminent predecessor; but he was certainly wrong in stating that Prof. Sedgwick had ever foretold that these ribs of porphyries were of pre-Cambrian age; he had, on the contrary, stated distinctly in some of his latest papers, in describing the Cambrian rocks between Bangor and Caernarvon, that they (the Cambrians) were "cut through by a great intrusive rib of syenitic porphyry of a different epoch," and in nearly the same words he described also the greater mass near Llanberis, &c. Again, he could not possibly believe with Prof. Hughes that faults or any other accidental cause could have produced the unconformity between the Dimetian and Pebidian. The two series are in every case, wherever exposed, unconformable to one another; and the presence of large angular masses of the Dimetian rocks continually in the agglomerates at the base of the Pebidian, together with the certainty that these agglomerates were for the most part cast out of a subaerial volcano, are, he thought, more than sufficient proof of physical changes at the time, which would be followed by a marked break in geological succession.

Prof. Hughes, in reply to Mr. Hicks, said he thought he might be pardoned for exhibiting some satisfaction at finding additional evidence of the accuracy of Prof. Sedgwick's original work, which had been so long under a cloud in that Society. As to the argument in favour of an unconformity between Pebidian and Dimetian from the occurrence of fragments of the older in the newer rocks, he said that, if he was right in considering the whole as one volcanic series, it was quite in accordance with what is observed in connexion with volcanic activity in modern times that fragments of any part of older volcanic accumulations, or of hardened necks and flows of lava, should be thrown out in subsequent eruptions,—and that the agglomerates of the Bangor and Pebidian rocks themselves agreed in containing numerous fragments which appeared to belong to the very series in which the agglomerates occurred. With regard to the possibility of its turning out that the pre-Cambrian volcanic series were only metamorphosed Cambrian, he pointed out that the lower part of the Cambrian series was well known; and if there were no other stratigraphical and petrological difficulties there would be this objection, that there was in the Cambrian of that district no sequence of beds at all corresponding to what would be required to furnish any thing like the Bangor group. In answer to a question by Mr. Maw, he said he thought that the only unconformity for which there was any evidence was at the base of the Cambrian Conglomerate and Grit.

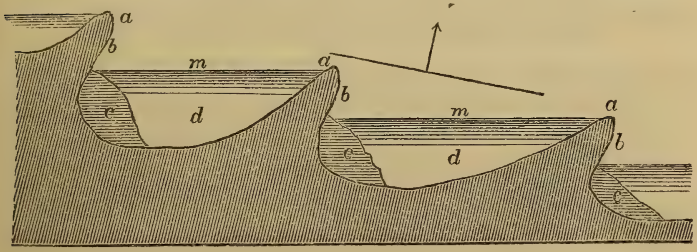
15. *On the* Building-up *of the* White Sinter Terraces *of* Roto-Màhànà. By the Rev. R. Abbay, M.A., F.G.S. (Read December 5, 1877.)

It is proposed in this paper to describe certain peculiarities in the structure of the "White Terrace" of Roto-Màhànà, in the Northern Island of New Zealand, which appeared to the writer, when visiting the spot in 1875, to be of considerable interest, as affording an explanation of the manner in which this most remarkable sinter formation has been built up. The geyser which has deposited the silica of which the terrace is formed, is situated on the side of a little hill of rotten rhyolitic rock, at an elevation of about 100 ft. above the warm lake (Roto-Màhànà) into which the foot of the terrace projects. The rim of the geyser is between 300 and 400 ft. in circumference; and the banks that surround it are steep on all sides except where the water finds an exit. Opposite this opening the wall of earth is almost perpendicular, and some 50 ft. in height. The geyser-basin is about 15 ft. deep, with a flat rim from 4 to 6 ft. broad, the whole being composed of a beautifully white flocculent-like deposit of silica, that yields slightly, like frozen snow, to the foot. The pipe is about 8 ft. in diameter, and is situated slightly on the exit side of the basin. A little rocky island, that will be referred to later, lies in the opening by which the water makes its escape, at about one third of the distance across it from the northern bank. It probably owes its existence to its exceptionally rocky character; for it is only 12 ft. in height, and has, no doubt, been separated from the neighbouring bank by the undermining action of the water. Below the geyser-rim the descent is broken up by a most remarkable series of terrace-basins formed by the deposition of silica as the water cooled in its passage to the lake. It is to the character of these basins that the writer wishes to direct attention. They number many hundreds, and are of various sizes and in different stages of formation. Some of them are sufficiently large and deep for half a dozen persons to swim in at the same time; others only occupy a space of a few square feet, and in some instances are filled up nearly to the brim by the deposited silica. Nearly all of them, I believe, can be referred to one main type of formation, however they may vary in appearance.

In considering the formation of so great a number of terrace-basins it must be remembered that the water issuing from the geyser-funnel, saturated with silica, has had to flow down an inclined surface about three acres in extent, and during this passage has cooled down from about boiling-point to something like 70° or 80° F. This latter temperature varies, of course, according to the amount of water issuing from the geyser and the temperature of the surrounding atmosphere. The colour of the water also varies very considerably at different parts of the terrace, showing that along with the cooling a continual precipitation of the silica in solution is going on. In the geyser-basin itself, and also in a few of the terrace-basins nearest to it, the water is of the most intense sapphire-blue. On the middle terraces it is like turquoise; and on the lowest it is partially opaque with a faint blue tinge. The contrast between the hoarfrost-like deposit of which nearly the whole terrace is formed, and the sapphire- and turquoise-coloured water in the basins, is most striking.

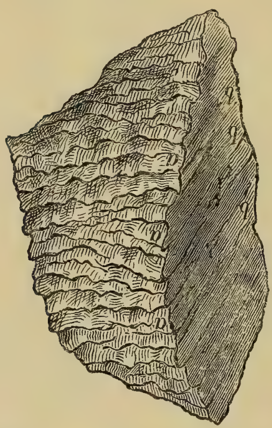
The precipitation and deposition of the silica being due to *the cooling of the water*, the same cause which operates to form the rim of the geyser-basin will also operate in a different degree after the water has begun to flow down the slope, and other rims more or less complete in form will be produced. These are the lips of the terrace-basins, or what appear from a distance to be the several terraces of the formation. Their shape is of necessity more or less circular; for if water, saturated at a high temperature with silica, issues from a geyser-pipe and spreads equally on all sides, becoming cooler as it proceeds, a point is reached at which a deposition of silica must take place in the form of a circular rim; and this once begun will of necessity continue until a distinct basin is produced; for the cooling will be greatest at the upper edge and on the outer wall of the rim, and it is there that the deposition will be greatest. When this basin has been built up until external obstacles on three sides compel the water to escape by the fourth, another rim, and if the slope is sufficient a series of rims, will be formed, which in turn will give rise to others. All these basin-rims are very similar in form, being approximately semicircular or, at least, arcs of circles. The water flows over each rim in a sheet of extreme evenness of depth, there being no difference perceptible by the eye over the whole extent of the rim, which in some cases is from 60 to 80 ft. in length. This strikes the visitor at first as somewhat remarkable; but a little consideration shows that it is a necessity of the case; for if any part of the rim through accident or otherwise be injured, it is evident that the water must flow through the opening thus made, and the injury be repaired before the other parts of the rim can be

Fig. 1.—*Section of Sinter Basins at Roto-Màhànà.*



augmented. It will perhaps be best, before describing the whole of the terrace more generally, to give an accurate description of one of the more strikingly typical terrace-basins. These, as has been said, are roughly semicircular and in appearance not unlike huge shells arranged with their edges horizontal. The wall of one basin slightly overhangs the water in the next, as will be seen by a reference to fig. 1, in which *a b* represents the overhanging wall, *a* being the upper edge of it; *c* is a somewhat flocculent deposit of silica left by the water that streams down *a b*; *d* is the main body of water within the basin; and *m* represents a stratum of water from 6 to 12 inches in depth flowing towards the lip, and of a considerably higher temperature than the mass of the water below it. The deepest part of the basin is generally about the middle; but this necessarily varies according as the water flowing into it comes from one or more basins, the deposit of silica *c* depending in shape, of course, on the water coming from these basins. On carefully examining the outer wall *b*, it is found to consist of a number of approximately horizontal ledges or minute basins (fig. 2), each of

Fig. 2.—*Block of Sinter.*



Half natural size.

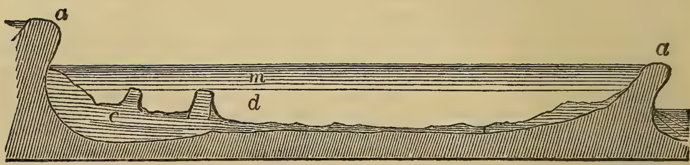
Showing the outer surface, with ridges forming miniature basins (*a*, *a*, *a*), and a fractured surface with parallel surfaces of deposition (*b*, *b*, *b*).

these apparently corresponding in miniature to the larger basin. It is evident that these are due to the deposition of silica on the edges as at *a a a*, and to the tendency to a greater growth at these points than elsewhere. A transverse section shows the parallel surfaces within the mass (*b b b*), thus proving that this system of deposition is regular. The above facts suggest to us what the process of building up these terrace-basins is, and what is the general effect on the whole mass of the sinter-formation. In the first place, the hot water flowing from *m* towards *a* (fig. 1) begins to be suddenly cooled on reaching *a*, and still more so on flowing down *a b*; for it is here exposed, in a thin sheet, to the chilling effects of the atmosphere. The deposit, therefore, chiefly takes place in these places, and the formation grows along the outer wall *b* and at the edge of the rim *a*. The effect of this is to raise the rim of the basin and to bulge it outwards. Again, the water passing down *a b*, immediately on entering the lower basin comes into contact to some extent with the cooler mass of water *d* underlying *m*, and the deposit *c* is formed. Thus, as the lip of the basin grows upwards and outwards at *a* and *b*, the basin thereby tending to become deeper, the deposit *c* has a tendency to advance into the basin and fill it up. Very numerous instances of this may be seen.

The resultant effect on any particular basin is evidently to make it grow upwards and outwards; and the general effect on the whole sinter formation is to thicken the deposit, somewhat irregularly perhaps, on the slope of the hill. This thickening will take place approximately along a normal to the general slope of the whole terrace at that particular point. It may be mentioned that the particular form of basin-structure described above is not found so distinct either where the water is at its hottest or at its coldest on the terraces—that is, in the highest and lowest portions. In the former case this, no doubt, results from the excessive deposition of flocculent silica *c* as compared with the upward growth of the rim *a*, due to the intermingling of the highly saturated and heated water that has just arrived with the cooler mass below. In the case of the lowest basins, where the slope is much more gradual and the deposition from the colder water much less in quantity, the growth of the rim proceeds scarcely more rapidly than the growth of the portion within it, which then assumes the character of a very gently sloping terrace bounded by a narrow rim only 2 or 3 inches in height. It may be noticed that the semicircular character of the rim, as well as the flocculent deposit in the basin, is very considerably modified according as the water flowing into it comes from one or more basins. In some cases as many as six or eight basins empty their water at slightly different temperatures into one, and the shape of this latter is modified accordingly. Where the water flows from a basin with a high outer wall, as it sometimes does, the tendency is for it to produce stalactitic forms in the lower, and the ordinary miniature forms in the upper part of the wall of this basin.

As to the rate of deposition at various parts of the terrace, this evidently depends very much on the temperature of the water; for leaves of plants, twigs, and other objects placed on the rims of the upper basins become thickly incrusted with silica within two or three days, whilst on the lowest portions of the terrace it takes as many weeks to produce the same result. The effect of this superior deposition from the hotter water is seen also in the greater breadth of the basin-walls, the water cooling most as it flows down the outer wall, and consequently depositing its silica more readily and thereby increasing the thickness of the walls. It may also be seen in the numerous flocculent masses of silica that stand up somewhat like small columns in the colder water *d* (fig. 3), but only reach up to the under surface of the hotter stratum *m*—a formation which only occurs in the upper basins, where the water is hottest.

Fig. 3.—*A Sinter Basin.*



Showing columnar elevations of the flocculent deposit *c*.

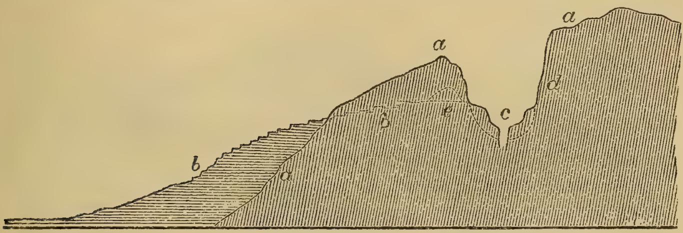
A reason for the existence of these columns is, I think, suggested by the analogy of the rain-clouds. It is well known that when two masses of air saturated with aqueous vapour at different temperatures intermingle, there is always a surplus amount of vapour over and above what is required for the complete saturation of the resultant mixture. This surplus vapour condenses and takes the form of a rain-cloud. In the same way, I think, when water saturated with silica at different temperatures, coming from two different basins, intermingles, an analogous process to condensation may come into operation, and a surplus precipitate of silica be formed in places where this intermingling chiefly takes place. If eddies are caused where the two currents intermingle, they may explain the occurrence of these curious little columns, which stand perfectly isolated in some of the basins.

As an instance of the effect of temperature in causing terrace-basins rather than flat terraces to be formed, it may be mentioned that, besides the facts already stated in regard to the lowest steps of the main terrace, which has been described, on the opposite side of the lake, at a distance of half a mile, is a second system of terraces, called the "Pink Terrace," in all about 80 ft. in height. The water issuing from the geyser belonging to this terrace is considerably below boiling-point; and, as a consequence, only a few of the topmost steps are in the form of basins, all the middle and lower ones being flat, and showing on the outer walls only the stalactitic forms already spoken of in connexion with the White Terrace, and not the peculiar structnre of the miniature basins.

It will be evident that the processes of building up the terrace-basins cannot go on long without some general effect being produced on the geyser itself; for the tendency is manifestly for the geyser to build itself in and thereby to be forced into and up the hill. Several facts appear to confirm the view that such changes have actually taken place. In the first place, the geyser-funnel is not situated on the natural slope of the hill, as one would expect if the geyser had broken out at its present elevation above the lake, but it is situated at some distance within the hill, as shown in fig. 4.

We have seen, too, from an examination of the terrace-basins, that both their individual growth and the growth of the whole terrace is *upwards* as well as outwards. Again, the earthy wall that sur-

Fig. 4.—*Section through the Geyser, showing its Position in the Hill.*



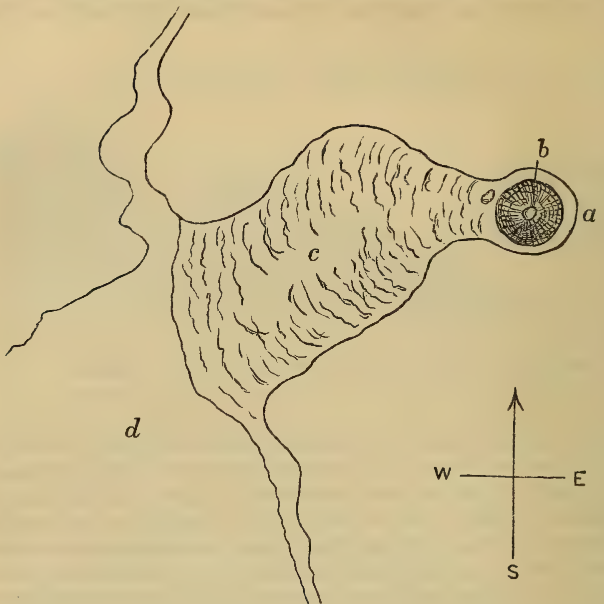
a a. Hill. *b b.* Sinter terrace. *c.* Geyser.
d. Cliff behind geyser. *e.* Rocky islet in the outlet.

rounds the geyser-basin, and especially that part of it which is opposite to the point of exit of the water, shows signs of continually falling in, as if the water were undermining it and letting it down, a condition of things that cannot fail, I imagine, to be brought about by the building up of the geyser-basin on the side from which the water issues. Lastly, the great size of the geyser basin (for it is 90 to 100 ft. in diameter) in comparison with the volume of water that flows from it, seems best explained on the supposition that the earthy cliff at the back (*d*), which is some 50 ft. in height, has so resisted the progress of the geyser into the hill, as to allow the earthy walls on either side to be eaten away, the result being an almost circular basin of the size described.

Against the above view may perhaps be urged the fact of the existence of the little rocky islet (*e*) in the very exit from the geyser-basin, on the supposition that it would have been undermined and carried away if the geyser had ever existed at a lower elevation, and had built itself up into the position which it now occupies. In reply to this it may be urged that the distance between the little island and the neighbouring bank is some 50 ft. (see fig. 5), a space amply sufficient for the existence of a geyser even of the size of this, if the water could find a more ready means of exit than at present exists. Besides this, the island is of a much more rocky character than the ordinary banks, and would without doubt offer greater resistance to disintegration than they have done.

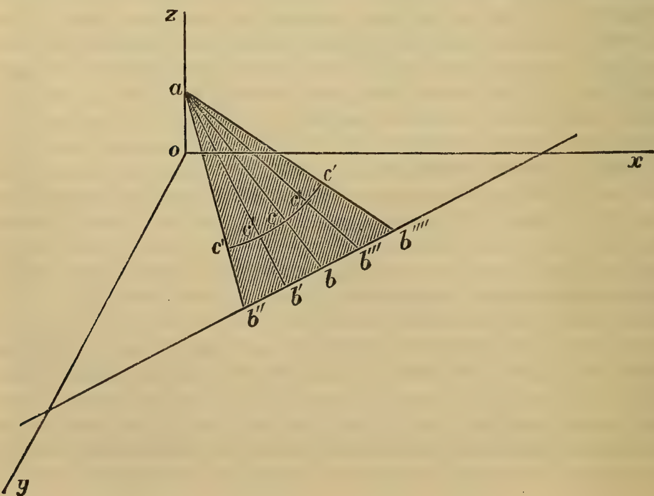
A few words are necessary to explain the manner in which the terrace-rims have originally begun to be formed, that is if we suppose the geyser has burst out on the natural slope of the hill. In fig. 6, let *a* be the point from which the hot water flows down the slopes *a b*. As it loses its heat during its progress a deposition of silica will take place; and if the water at first flows in a narrow channel, this must in time be filled up by the de-

Fig. 5.—*Plan of the Geyser-basin and Terrace.*



a. Hill, *b.* Geyser-basin. *c.* Sinter terrace. *d.* Lake.

Fig. 6.—*Diagram showing the Mode of Deposition of the Sinter.*



posited silica; and the water will then spread itself over a larger area, whose depressions will also be filled up until an inclined surface will be presented, over which the water will flow, as in the directions $a\,b'$, $a\,b''$, $a\,b'''$, $a\,b''''$. The sheet of water becoming rapidly thinner as it spreads itself out in the form of a fan, the cooling will be much more rapid, on account of the greater surface exposed to the influence of the atmosphere. Consequently points will soon be reached equidistant from a, such as $c\,c'\,c'$, where the silica will begin to be rapidly deposited. Thus a rim will be formed, necessarily in the shape of an arc of a circle, as $c'\,c\,c'$, with a as its centre. This rim once begun, the deposition of silica, as we have already seen, goes on most readily on the outer wall of the rim, as at b, fig. 1; and consequently a basin will be formed, to be modified afterwards in various ways as is seen in figs. 1 & 3.

If the water flows over the rim $c'\,c\,c'$ with perfect evenness of depth, another rim will be formed below concentric with the one above, and with a as its centre. This, however, is rarely or never seen. The water in flowing down the wall of the basin generally becomes somewhat uneven in depth, owing to slight irregularities on its surface; and the consequence is that the sheet of water has a tendency to divide itself into different currents, and thus to form different basins. To take an exaggerated case, we may suppose five different currents to start from $c'\,c'\,c\,c'\,c'$ (fig. 6), and to form five different rims, each in the form of an arc of a circle and intersecting one another.

Discussion.

Dr. Evans asked whether the deposit described consists of pure silica, and what is the nature of the rock through which the water depositing it percolates. It seemed to him to be hardly likely that the water could be that of the lake circulating through the rock, as, if so, it could hardly acquire so high a temperature or so large an amount of silica. He also inquired whether there are any cavities in the rocks, especially containing geodes, and whether there is any known law as to the solubility of silica in water of different temperatures.

Prof. Ramsay inquired whether this was a spouting geyser.

Mr. Drew questioned whether the silica deposited could be redissolved in the manner required by the author's hypothesis; and inquired why, supposing the author's hypothesis to be correct, the deposit from the geyser does not form a dome.

Prof. Ramsay remarked upon the great depth to which the water must probably descend in order to acquire the temperature necessary for dissolving the quantity of silica described.

Mr. Sollas asked if there were any data as to the relation of pressure as well as temperature to the solubility of silica.

Mr. J. F. Walker referred the re-solution of the silica to the action of superheated steam.

Mr. Whitaker considered that the fact of these springs breaking out on a hill-side would account for the absence of domes such as were referred to by Mr. Drew, the springs forming domes being generally, if not always, on flat ground.

The Author, in reply to a question from the President, stated that an analysis of the sinter gave:—

Silica	86·0
Water and organic matter	11·5
Sesquioxide of iron and alumina	1·31
Lime	0·45
Magnesia	0·4
Alkalies	0·38

He stated that upon a line running from Tongariro, a volcano always in action, towards Mayor Island, many volcanic phenomena are observed, such as mud-volcanoes and geysers, and here spouting geysers are met with, although these only spout occasionally; and it was remarkable that, as reported in the district, those geysers only spout when the wind is in the east. He had found by experiment that chloride of sodium does exert some solvent action upon the silica of the sinter; but nevertheless the notion of the re-solution of the silica in the geyser-pipe was put forward by him merely as a suggestion. The rock forming the hill in which the geyser rises is rhyolitic; and the whole country is covered with pumice.

16. *On the* Stratigraphical Position *of the* Corals *of the* Lias *of the* Midland *and* Western Counties *of* England *and of* South Wales. By Robert F. Tomes, Esq., F.G.S. (Read May 9, 1877.)

[Plate IX.]

Introduction.—The following stratigraphical list of Lias corals must not be regarded as by any means a complete one, even for the district above mentioned, but rather as a record of such species as I have either collected myself, or such as have been collected within my knowledge, and of which I can therefore speak definitely. This will perhaps afford a sufficient reason for the somewhat personal mode of expression made use of throughout the paper. The nomenclature for horizons which I adopt may possibly be regarded as rather antiquated. For instance, instead of speaking of the zones of *Ammonites angulatus* and *A. Bucklandi*, the words "*Lima*-beds" are often used. This is done advisedly, and for the following reasons:—*Ammonites Bucklandi* is a very rare species throughout the midland counties, and it becomes therefore an uncertain guide. And although *Ammonites angulatus* is abundant enough; its vertical range is so great that, unless assisted by other associate organisms, it becomes practically useless in determining the stratigraphical position of a coral. The greater number of *Isastrææ* and *Septastrææ* occur in a rather restricted bed underlying the so-called *Lima*-beds; and in this *Ammonites angulatus* occurs abundantly. But it also appears up through the whole of the *Lima*-series, though less abundantly, and through the clays containing *Ammonites semicostatus* and *A. Turneri* *, and upwards to the top of the zone in which *A. planicostatus* and *Hippopodium ponderosum* appear. From this zone I have myself taken it at the north-west end of Welford Hill, four miles west of Stratford-on-Avon. But wherever I have found *A. angulatus abundant*, and *associated with Cardinia ovalis*, there I have often been successful in my search for the species of *Isastræa* and *Septastræa*; and this has, in almost every instance, been immediately under the beds which contain the large *Lima* (*L. gigantea*) in the greatest abundance. Hence my reason for adding the testimony of the *Lima* and *Cardinia* to that of the Ammonite.

Many of the species in this list have been described and figured by Dr. Duncan in the volumes of the Palæontographical Society, from specimens taken from localities here mentioned; and the more ample stratigraphical information herein contained will therefore be a useful addition to his valuable monograph.

As might be anticipated, with greater attention paid to the corals of the Lias, several new species have been met with, more especially

* The great vertical range of *Ammonites angulatus* has also been noticed by Mr. Moore, who found it high up on the Bridgend section, South Wales, associated with *A. semicostatus* and *A. Sauzeanus*. See Quart. Journ. Geol. Soc. vol. xiii. p. 511.

in the Marlstone of the Middle Lias. Some of these are here described, and they are specially interesting as showing a *facies* quite distinct from that of the Lower-Lias Corals. I am not aware that any of the *Fungidæ* have hitherto been discovered in the Lias of this country. Three genera of these, however, I have met with, and they will be described in their proper places. Throughout the paper no classification is introduced other than that of commencing with the older forms, and proceeding in successive order to the more recent, and the division of the species into the families Astreidæ and Fungidæ.

As this communication is professedly a record of observations made in the field rather than an expression of opinion of the works of others, I confine my notice of the corals from the Brocastle, Sutton, and Dunraven Lias, in South Wales, within the limits of this introductory part. Their stratigraphical position has been so often discussed that little more need be said about them; and I shall therefore only notice the several papers which have been written on these deposits. The first was by myself, and appeared in the 'Proceedings of the Cotteswold Naturalists' Field Club' in 1863. In it I ventured the opinion that the Rhætic formation is there represented by an interval during which no deposit of earthy matter took place, and that the Rhætic fauna of that period became in this manner mixed up with that of the true Lias, which was subsequently deposited. Three years afterwards, in 1866, Mr. Tawney published, in the 'Quarterly Journal of the Geological Society,' a paper on the Rhætic beds and Sutton Stone of South Wales, in which a much fuller Rhætic interpretation was given to these deposits. In the following year, 1867, appeared in quick succession papers by Dr. Duncan, Mr. Bristow, Mr. C. Moore, and Mr. Tate, all of whom may be said to have advanced anti-Rhætic opinions. They are chiefly of opinion that these deposits are true Lias, and referable to the zone of *Ammonites angulatus*. Of this I must confess that I am not yet fully convinced; but should that prove to be the correct interpretation, the coral fauna of that zone, taking into account all the known localities, will be a most remarkable one, not merely from the number of species, but also from the great diversity of forms which they exhibit. The species which I obtained at Brocastle and from the Sutton stone in 1863 were the following:—*Thecosmilia rugosa*, *T. dentata*, *Cyathocœnia incrustans*, *C. dendroides*, *Astrocœnia parasitica*, *A. superba*, *A. minuta*, *A. insignis*, *A. costata*, *A. gibbosa*, *Isastrœa globosa*, *I. sinemuriensis*, *Septastrœa excavata*, *Elysastrœa Fischeri*, *E. Moorei*, and *Montlivaltia pedunculata*. These have been described by Dr. Duncan in the volume of the Palæontographical Society for 1867; and by means of his descriptions and figures I have been enabled to make out the foregoing list.

List of Species.

Fam. Astreidæ.

Montlivaltia rhætica, n. s.

Since the appearance of Dr. Duncan's 'Supplement to the British

Liassic Corals' in 1867, some better-preserved specimens of a species of *Montivaltia*, of which he gave a woodcut, have been obtained. The illustration was taken from a cast of the calice, which came from the White Lias at Print Hill, Warwickshire. Dr. Duncan believed that it belonged either to *Montlivaltia Haimei* or to one of its varieties. After a careful examination of a great many specimens, I have arrived at the conclusion that it is quite distinct from that species; and I describe it thus:—

Wall basal, and either flat or concave inferiorly, in no instance showing any tendency to enclose the calice, which is quite open laterally. It is thin, and exhibits but little appearance of concentric markings. Calice evenly but very moderately convex, extending laterally beyond the wall, and with but little appearance of a central fossula. There are four cycles of septa, and a fifth which is merely rudimentary. The primary ones are strongly developed, and meet and unite in the centre, but they do not there form a spurious columella. The secondary ones are much less strongly marked and less exsert than the primary ones, but reach to near the centre; and the tertiary ones attain to two thirds of the length of the primary ones. They all have their superior margin papillated; but the papillæ are not half so numerous or so regular as in *Montlivaltia Haimei*, Chap. et Dewal. The largest specimen I have seen has a diameter of $\frac{3}{4}$ of an inch. Smaller examples show a more simple septal arrangement, and have only three cycles; and in these the primary septa are so large as to present something of the star-like aspect of the calice of *Montlivaltia radiata*, Duncan.

In general form this coral much more nearly resembles *Montlivaltia nummiformis*, Duncan, than any other Liassic species; but it is to the Oolitic species *Montlivaltia lens* that it bears the greatest general resemblance.

It has been found in the White Lias at the following places:—in Warwickshire, at Harbury, Stoneythorpe, Print Hill, Long Itchington, Eatington, Wimpston, and Stockton; in Worcestershire, at Armscot; and in Somersetshire and Dorsetshire, at Marshall's Elm near Street, and Pinhay Bay. I also obtained a specimen from Penarth Head in 1860.

Thecosmilia Terquemi, Duncan, Supp. Brit Foss. Corals, pt. iv. no. 1 p. 16, pl. iii. figs. 7–12, 1867.

In 1860 Dr. Wright communicated to the Geological Society his paper on the Lower Lias of the South of England, in which he gave a section of a quarry in the *Planorbis*-beds at Binton, in Worcestershire. It had been prepared by myself; but I had afterwards an opportunity of adding considerably to the list of fossils in the bottom beds, and of following the section considerably lower down. The lower part of the section I now give, to show the position of *Thecosmilia Terquemi* in it.

Binton.

	ft. in.	
Paving-beds, finely laminated, stone and shale.	16 0	*Ammonites planorbis*, var. *Johnstoni*, Insects, *Eryon barroviensis*, *Pholidophorus Stricklandi*, *Tetragonolepis*.
"Griesley bed," a light pepper-and-salt-coloured bed, not laminated, but very constant.	0 1½	Composed of comminuted shells (a species of *Lima* and *Ostrea liassica*), fish-scales, saurian bones, species of *Cidaris* in abundance, *Pentacrinites*, *Ammonites Johnstoni*.
"Blue stone" of a uniform clear blue, not laminated.	0 7	Saurian remains rare; the elytron of a beetle in one instance.
Similar to the last, but not named.	0 6	No fossil ever seen in this bed.
"Grave-stone bed," a hard dark stone.	0 5	Bones and skeletons of Saurians, *Otopteris acuminata*, *Eryon barroviensis*.
Shale.	0 3	
"Pendles," a hard crystalline stone.	0 1	*Ostrea liassica* in extreme abundance.
"Firestone," a very hard crystalline stone abounding in shells.	0 8	*Ammonites Johnstoni* (one specimen on the upper surface of the stones), *Placunopsis alpina*, *Ostrea liassica* abundant, *Modiola minima*, *Myacites musculus*, *Pholadomya prima*, *Arca*, *Astarte*, *Gervillia*, *Cardium*, *Pecten*, *Perna infraliassica*, *Otopteris obtusa*.
Stone, intermittent.	0 1½	No fossils.
"Bottom blue-stone," intermittent.	0 1½	*Monotis decussata*.
Shale.	0 3	
"Guinea-bed," hard and crystalline, so called because the stones, when dry, ring when struck.	1 0	*Avicula longicostata*, *Anoplophora musculoides*, *Monotis decussata*, *Cardinia depressa*, *Ostrea liassica*, *O. intusstriata*, *Placunopsis alpina*, *Axinus*, *Sargodon tomicus*, *Hempedina Tomesi*, *Thecosmilia Terquemi* growing on the top of this bed.
Clay of a light greenish grey colour.	8 0	No fossils.
"Maums," or "White lumps," in all respects like the *Estheria*-bed of Westbury-on-Severn.	0 8	*Estheria* in crowded masses.
Clay of a greenish colour, depth not ascertained.		

Similar stunted *Thecosmiliæ* have occurred in the same bed at Wilmcote, near Stratford-on-Avon, and they correspond very well with the *Thecosmilia Terquemi* of Dr. Duncan.

At Street, Somersetshire, a small *Thecosmilia* occurs which may perhaps be the same species. It was found by myself in 1860 in the same quarry which supplied Dr. Wright with the *Isastræa* since described by Dr. Duncan under the name of *Isastræa latimæandroidea* *, and the following section made at the time will show the position of both corals.

Cree's Quarry, Street.

	ft. in.	
Surface-soil.	1 6	
"White bed," shattered stone.	0 6	*Ammonites planorbis.*
White clay.	1 6	*Ammonites planorbis.*
Rust-coloured shale.	0 3	*Ichthyosaurus*, ISASTRÆA LATIMÆANDROIDEA, Duncan, SEPTASTRÆA HAIMEI ?, Wright, sp.
Coarsely laminated grey shale.	1 4	
"Rich," imperfect stone.	0 4	*Ostrea liassica*, *Ammonites planorbis* in great abundance.
"Top rock," a hard blue stone.	0 7	*Ammonites planorbis* on its upper surface only. THECOSMILIA in fragments scattered through the stone, *Waldheimia*, *Astarte.*
Dark shale.	0 3	*Ichthyosaurus.*
"Corn size," a hard blue stone.	0 6	*Lima punctata*, *Pinna.*
Dark shale.		
"Bunch-backs," a hard blue stone.	0 5	*Modiola minima*, *Ostrea liassica*, *Arca*, *Cardium*, *Lima punctata.*
Dark shales.	0 3	The species in this bed correspond with those of the *Ostrea*-bed of other localities.
"Clay bats," sometimes hard stones.		

I afterwards found the same coral, in the same disjointed condition, in blocks of stone in every respect similar, at a place called Marshall's Elm, near Street. It was probably a small species (if not young examples of the last), none of the fragments exceeding an inch in length, and the third of an inch in the diameter of the calice. The horizontal sections in the stone show the septa very clearly.

* Supp. Brit. Foss. Corals, pt. iv. No. 2, p. 65, pl. xv. figs. 18, 19 (1868).

The walls and septa are very thin; and the latter are not more than about twenty in number, and they none of them reach to the middle of the calice. These sections appear to be those of a coral quite as much like *Cladophyllia* as *Thecosmilia*; but outwardly the fragments much resemble fig. 2 of *T. Martini*, given by Terquem and Piette at pl. xxii.

Isastræa latimæandroidea, Dunc.? Supp. Brit. Foss. Corals, pt. iv. no. 2, p. 65, pl. xv. figs. 18, 19 (1868).

In a stone-quarry near to Temple Grafton, Warwickshire, I met with a portion of an *Isastræa*, which, from the form of the calices, and the abundance of its marginal gemmation, may probably be referred to this species. The following section will show its position in the quarry:—

Hendley's Quarry, Grafton.

	ft. in.	
Surface soil.	4 0	
Dark grey stratified but not laminated shale.	6 0	
"Rusty bed," a thin band of dark grey stony shale with a ragged fracture, often pyritic, and decomposed into rust, very persistent in the district.	0 3	*Ammonites Johnstoni*, *Nautilus*, *Lima gigantea*, *L. antiquata*, *Cardinia ovalis*, *Arca*, *Ostrea irregularis*, a small smooth *Pecten*, *Astarte*, spines and plates of *Cidaris Edwardsi*, Isastræa latimæandroidea ?, Dunc.
Laminated beds, stone and shale, succeeded below by the "Griesley-bed, *Ostrea*-bed, &c., depth not taken.		Saurians, Insects, *Ammonites Johnstoni.*

An *Isastræa* has also occurred in a quarry at Binton, very near to, if not in the "rusty bed." It had been taken with the clay by the workmen, and used to bank up a burning lime-kiln; and when I saw it fire and water had reduced it to lime.

Isastræa Tomesi, Duncan, Supp. Brit. Foss. Corals, pt. iv. no. 2, p. 46, pl. 15. fig. 20.

The quarry at Temple Grafton, of which I have given the section, is situated half a mile south-west of a low hill or ridge, on the top of which the plough brings up the beds of nodular stone known in Warwickshire as the *Lima*-beds, and containing the *Lima gigantea* in abundance. The bottom beds crop out halfway up the hill; and in them *Cardinia ovalis* is plentiful, and examples of *Ammonites angulatus* by no means rare. Immediately under this bed, in the clay, I met with the type specimen, just below a plantation called "the Long Coppice."

Another and larger specimen was taken by me from the Bishopton-Hill cutting on the Stratford and Hatton Railway, which passed through the lower part of the *Lima*-beds. Its precise position I am unable to give.

The calices of this larger specimen being in a better state of preservation than those of the specimen described by Dr. Duncan, enable me to add the following:—

The corallum would be symmetrically balloon-shaped, excepting for a lobe at its base. Height 9 inches, base attached to a mass of oysters (*Ostrea irregularis*). Calices somewhat larger than in the type specimen. Walls thin, but their extreme margins thickened and smooth; and this thickened part passes down many of the septa, and spreads out where they meet in the centre and are fused together, forming an irregularly shaped prominence, which is as high in some of the calices as the walls themselves. I think this thickening and filling up of the calices is merely the result of excess of endothecal structure, which is everywhere visible in the interseptal loculi.

Isastræa Stricklandi, Duncan, Supp. Brit. Foss. Cor. pt. iv. no. 2, p. 54, pl. xiii. figs. 1–2.

This species, although assigned by Dr. Duncan to the zone of *Ammonites Bucklandi*, is, I believe, confined to that of *A. angulatus*. A considerable number of specimens were at one time obtained from a brickyard at Chadbury, near Evesham; and this excavation lay in the very heart of the latter zone. It was a very fossiliferous deposit of dark blue clay, in which the organic remains were well preserved. From it I took most beautiful and large examples of *Cardinia ovalis*, and typical specimens of *Ammonites angulatus*. Chadbury Hill, in contiguity to the brickyard, is capped with the so-called *Lima*-beds, as at Grafton and Binton.

Septastræa Eveshami, Duncan, Supp. Brit. Foss. Cor. pt. iv. no. 2, p. 52, pl. xiii. figs. 5, 6.

My friend the Rev. P. B. Brodie took this coral from a cutting in the Oxford, Worcester, and Wolverhampton Railway, near to Fladbury, where the lime passes through the same bed as that in which the last species was found. Mr. Brodie, however, informs me that, so far as he remembers, no fossil was found associated with it.

Thecosmilia Michelini, Terq. et Piette, Lias Inf. de l'est de la France, p. 127, pl. xvii. figs. 7, 8.

I have collected this species in abundance at St. Bride's, near Bridgend, but am quite unable to assign it a definite place in the Lias there. In 1841 Mr. Strickland gave an account of the cuttings of the Birmingham and Gloucester Railway in the 'Transactions of the Geological Society.' At page 551 he mentions "a *Caryophyllæa*" as occurring about a mile south of Norton, near Worcester; and he adds, "which is remarkable from the general scarcity of corals in the Lias formation." Just twenty years after, in 1861, I visited the spot, and found in a clay bank of about 3 feet an irregular stony layer, in which were pieces of a long branching coral in abundance. Every fragment of stone contained ill-preserved pieces of what I then believed to be a *Cladophyllia*. Broken-up branches were equally numerous in the clay itself; but none of them were more than casts. The few small fragments which show any structure have a low septal number; and most likely the species is identical with *Thecosmilia Michelini*. The presence of *Ammonites angulatus* with these corals leaves no doubt as to their position in the Lias.

THECOSMILIA MARTINI, E. de From. in Paléont. Stratigr. de l'Infra-Lias de la Côte-d'or, par Jules Martin, Mém. Soc. Géol. Fr. 2e sér. tome vii. p. 92, pl. viii.

At Down Hatherley, Gloucestershire, Mr. Brodie found a species of *Thecosmilia* which I have little hesitation, after the examination of a considerable number of specimens, in referring to the above species. In the figure given by De Fromentel the septa meet in the centre; and in this respect the Down-Hatherley coral more nearly resembles the French than the English examples figured by Dr. Duncan. It was found associated with a globular *Isastræa* and the following mollusca—"*Cardinia ovalis*, *Lima gigantea*, *Modiola*, *Astarte consobrina*, and many univalves."

MONTLIVALTIA RUPERTI, Duncan, Supp. Brit. Foss. Cor. pt. iv. No. 2, p. 46, pl. xii. figs. 3, 4, 5, pl. xv. fig. 15.

The specimens from which Dr. Duncan took his description were all collected by Mr. Brodie at Down Hatherley, but were not associated with the *Isastræa* and *Thecosmilia*. He says, "I found the last, *M. Ruperti*, when the new school was being built at Down Hatherley, near the Vicarage, really at a lower level than the spot where I found the *Thecosmilia* and *Isastræa*, and also in the brook below, still lower down as regards level, though stratigraphically higher, owing to a slight dip of the beds and partial upthrow." The only associated fossil mentioned by Mr. Brodie is *Cardinia crassiuscula*.

MONTLIVALTIA PATULA, Duncan, Supp. Brit. Foss. Cor. pt. iv. No. 2, p. 56, pl. xv. figs. 6, 7, 8.

The zone in which this species occurs, near my former residence at Welford Hill, is a remarkably restricted one. It is at the top of the bed containing *Ammonites semicostatus* and *A. Sauzeanus*, which is not there more than six inches in thickness. All the examples found were in a thin intermittent band of stone, ragged with the number of shells which it contained. A few feet higher up the hill-side *Ammonites Birchii*, *A. Brookii*, and *A. planicostatus* appear.

At Pebworth, about three miles to the south-west, I found some *Montlivaltiæ* which Dr. Duncan considered identical with *Montlivaltia mucronata*, observing, however, that they had grown under less favourable circumstances than the Fenny-Compton examples*—an opinion in which I myself at one time concurred. But the acquisition of better-preserved specimens has led me to a different conclusion. When the calice of these Pebworth corals is perfect it resembles that of *Montlivaltia patula*, but bears little resemblance to that of *Montlivaltia mucronata*. Of course the turbinate form of this coral does not identify it with *M. mucronata* any more than with *Montlivaltia Ruperti* or *Montlivaltia sinemuriensis* of D'Orbigny, both of which are turbinate species. At Pebworth, as at Welford Hill, the corals occur on the top of the bed containing *Ammonites semicostatus* and *A. Sauzeanus*. I entertain no doubt that the Pebworth corals are old examples of *Montlivaltia patula*, though some of them in external form bear considerable resemblance to *Montlivaltia polymorpha*.

Thecosmilia socialis, n. s. (Pl. IX. figs. 5, 6.)

This new and interesting species was taken by myself from a quarry between the railway-cutting and the town of Bridgend, Glamorganshire, in 1863. It was found *in situ*; and in the same stone bed were examples of *Ammonites semicostatus* and *A. Sauzeanus*. I have seen but one specimen, and I describe it thus:—

Corallum of a more or less globular form, but somewhat depressed, and attached by the centre of its base. The upper half consists of the calicular surface; and the lower half is surrounded by a common epitheca, which, near to the margins of the calices, curves inwards and half surrounds them. It is thick, rugose, and concentrically wrinkled. The calices are fifteen in number, and have a diameter of about a quarter of an inch; the central ones are rudely five-sided, but the outer ones are nearly round. They are of medium depth. The septa of the contiguous calices spring from the walls exactly opposite to each other. They are straight, and retain their thickness as they approach the centre. In the smaller calices there are only three cycles; but in the larger ones there are as many as five. Those of the first reach the centre but do not unite; those of the second are nearly as long as those of the first; those of the third nearly as long as the second; and those of the fourth and fifth scarcely half the length of those of the third. The septa of the first and second cycles have their margin armed with about six well-marked sub-pointed vertical processes, those nearest the centre of the calice being the most prominent. The dissepiments are not very numerous, but are well developed and have a somewhat tabular arrangement.

Height of the corallum	1 inch.
Greatest diameter	$1\frac{1}{2}$ inch.

Montlivaltia rugosa, Wright, sp.

Thecocyathus rugosus, Wright, Quart. Journ. Geol. Soc. vol. xvi. 1860, p. 411. (No. description given.)

* Supp. Brit. Foss. Cor. pt. iv. No. 2, p. 58.

Montlivaltia rugosa, Duncan, Supp. Brit. Foss. Cor. pt. iv. No. 2, p. 58, pl. xiv. figs. 1, 2, 3, pl. xv. figs. 14, 16, 17, pl. xvi. figs. 5, 15.

This species, first noticed by Dr. Wright near Cheltenham, has been subsequently found at several other places. It occurred in great numbers in a cutting of the Stratford-on-Avon and Honeybourne Railway, near the latter place. All the examples were confined to a brown-mud bed, about a yard in thickness, in which every thing appeared to be rotten; but it occurred in greatest abundance in the bottom of the bed, and a great many were in an upright position. I found as many as five attached by their bases to the valve of a large *Pinna*. Others were found growing on Gryphites, *Limæ*, and other shells, and even on dead and waterworn specimens of their own kind. They were so numerous that a bushel might very easily have been obtained when the cutting was in progress; but from the rottenness of the bed it was difficult to meet with a perfect specimen. In this mud-bed were numerous half-decayed examples of *Ammonites densinodus*, *A. armatus*, and *A. nodulosus*; and under it, in a hard blue marly shale, were well-preserved examples of *Ammonites Guibalianus* or an allied species. I have a specimen of this coral given to me by Mr. G. E. Gavey, from a cutting at Aston Magna, near Moreton-in-Marsh, Gloucestershire, where it was associated with *Ammonites armatus* (young), numerous Gasteropoda, endless numbers of *Spiriferina rostrata*, and a few examples of *Montlivaltia mucronata*.

In 1861 I found a single example lying in the bottom of the clay-pit of a brickyard at Hill Morton, near Rugby, where many examples of *Ammonites densinodus* and *A. armatus* were scattered about. Another specimen has been found near Leicester; but I know nothing of its associated fossils. I have seen a very young example of a coral in all respects like the young examples from Honeybourne, growing on a Gryphite, which was found by my friend Mr. Beesley in the Fenny-Compton railway-cutting.

Montlivaltia mucronata, Duncan, Supp. Brit. Foss. Cor. pt. iv. No. 2, p. 59, pl. xiv. figs. 4–11 & 14–16, pl. xv. figs. 10–13.

The first mention of this species, or indeed of any other coral, in the Lias of this country, was made in 1822 by Coneybeare and Phillips in their 'Outlines of the Geology of England and Wales,' where it is called "a species of *Turbinolia*" which "occurs in the upper beds of the Lias formation, especially at Fenny-Compton Tunnel on the Oxford canal." No other specimen of the Fenny-Compton corals are recorded until about 1859, when, in company with my friend Mr. Etheridge, Mr. Kershaw, and Mr. Brodie, I picked up a solitary example on the spoil bank of the canal. This suggested an examination of the adjacent railway-cutting; and in a slip of earth there several other specimens were speedily obtained. Since that time, during the construction of the East and West Junction Railway through the same bed, it has been so abundant that many hundreds have been collected. During one visit there I picked up more than two hundred specimens. The coral-bed at this place is from one to two feet thick; but its precise position in relation to the coral-beds of Honeybourn, Aston Magna, Hill Morton, and Cheltenham I have failed to ascertain. The coral is associated with *Terebratula numismalis*, *Pecten priscus*, *Gryphæa obliquata*, *Ammonites armatus* (young), and *A. Jamesoni*. The presence of the latter in the coral-bed, where it was found by my friend Mr. Beesley, of Banbury, removes the *Montlivaltia mucronata* from the Lower to the Middle Lias. Yet Mr. G. E. Gavey found this species and *Montlivaltia rugosa* together at Aston Magna; and I think there is no doubt that both occur at Fenny Compton. Besides these localities, I am able to add Kilsby, in Northamptonshire, near Bredon, Gloucestershire, Blockley Station, on the Oxford, Worcester, and Wolverhampton Railway in Worcestershire; and a specimen in the British Museum is labelled Kettering.

Montlivaltia nummiformis, Duncan, Supp. Brit. Foss. Cor. pt. iv. No. 2, pl. xiv. figs. 12, 13.

Occurs with the last species at Fenny Compton, and is rare.

Montlivaltia radiata, Duncan, Supp. Brit. Foss. Cor. pt. iv. No. 2, p. 61, pl. xv. figs. 1–5.

With *Montlivaltia mucronata* at Fenny Compton, rare.

Montlivaltia Victoriæ, Duncan, Supp. Brit. Foss. Cor. pt. iv. No. 2, p. 63, pl. xvii. figs. 1–10.

The first examples of this fine species were obtained at Cherrington, near Shipston-on-Stour by the late Mr. Richard Lamley, of Tredington, near that place. Others have subsequently been met with in abundance by Mr. Beesley in the Middle Lias near Banbury, where they were associated with *Ammonites ibex*.

I have now to add another locality, viz. Charmouth, three examples having been found in the tumbled masses of Middle Lias on the beach; but their position in the cliff section has not been ascertained.

Fam. Fungidæ.

The species which I have now to describe was taken by me from a large mass of tumbled Middle Lias on the beach under the cliff at Charmouth, a little eastward of the spot where the beautiful examples of *Ophioderma Egertoni* are found. On the same surface of the block, and in near proximity to each other, were the following fossils—*Plicatula spinosa*, *Rhynchonella tetrahedra*, a well-preserved and typical example of *Ammonites margaritatus*, a fragment of a *Montlivaltia* with thick septa, and the present species. The presence of the above Ammonite would alone be conclusive evidence that it is a genuine Middle-Lias species. I believe that it represents a new genus, and describe it as follows:—

TRICYCLOSERIS, n. g.

Corallum composite, depressed; calices few in number, in the centre of the calicular surface, and arranged in a line. Septa very numerous, straight and anastomosing. Synapticula well developed.

This genus may be briefly described as a compound *Cyclolite*, having a series of calices occupying the linear space ordinarily occupied by the elongated fossula. In the only example yet obtained there are three calices only.

TRICYCLOSERIS ANNINGI, n. s. (Pl. IX. fig. 1.)

Corallum depressed, with an irregular upper surface, highest in the middle, the outer margin thin, broadly lobed, and slightly everted. Under surface irregularly concave, and without an epitheca.

Calices three in number, in a curved line in the middle of the calicular surface.

There is no fossula.

The septa are equal, thin, straight, numerous, and anastomosing, and they meet in the centre of the calices.

The interseptal spaces are not more than half the thickness of the septa.

Synapticulæ numerous and well developed.

Height of the corallum $\frac{1}{2}$ an inch.

Its greatest diameter $1\frac{1}{2}$ inch.

THAMNASTRÆA ETHERIDGEI, n. s. (Pl. IX. fig. 4.)

The corallum is massive, and probably adherent. In the smaller examples it is more or less rounded in outline, but in the larger ones more irregular, in all the upper surface is pretty evenly convex.

Basal plate presenting indications of intermittent growth. Epitheca rudimentary, costal striæ very indistinct. Calices rather large, shallow, equal, regular in outline, and approximate, with a tendency to a serial arrangement. Septa numerous, rather thin, regular, and retaining their thickness as they approach the columella. The cycles are rather difficult to trace, but there are probably four, the septa being about thirty in number. The columella is composed of papillæ, and very irregular in its degree of development. The largest specimen is about $2\frac{1}{2}$ inches in diameter. With weathering the walls become more apparent (though the septa of proximate calices are still confluent), and the columella is almost lost. The calices then look larger.

This species occurs in the Middle Lias at King's Sutton, about three miles S.S.E. of Banbury, at which place and at Adderbury (also near to Banbury) the marlstone of the Middle Lias is remarkably fossiliferous. It has been specially studied by Mr. Beesley, who communicated a very interesting paper on this and other Liassic strata, which was read at the Annual Meeting of the

Warwickshire Naturalists' and Archæologists' Field Club in 1872. Since that time a very considerable series of fossils has been obtained from these King's-Sutton beds. Amongst them are the following:—

Ammonites spinatus, not uncommon.
—— margaritatus, not uncommon.
Harpax Parkinsoni.
Spiriferina oxygona.
Pecten textorius.
Cidaris amaltheus.

With these are associated examples of the species of coral I have here described, and three others, two of which are also described here. The third one is a *Thecosmilia*; but the examples which have hitherto been met with are not sufficiently preserved to admit of description.

Cyclolites cupuliformis, n. s. (Pl. IX. figs. 2 & 3.)

Corallum of a depressed cup-shape, rounded beneath, and having a slight constriction immediately under the calicular margin.

Calicular margin projecting, rounded, and a little everted.

Calice ovoid and a little concave. Fossula central, small, abrupt, deep, and elongated in the direction of the longest diameter of the calice.

Septa exceedingly numerous, thin, straight, equal, and moniliform, and so closely placed together that no interval is visible between them.

There is no epitheca.

Height of the corallum 9 lines.

Greatest diameter of the calice 1 inch 4 lines.

Two specimens have been obtained from the Middle Lias of King's Sutton, Northamptonshire—one of them by myself and the other by Mr. J. Griffin. They were associated with the same Mollusca as the species I have described as *Thamnastræa Etheridgi*.

Astreidæ.

Montlivaltia foliacea, n. s. (Pl. IX. fig. 10.)

Corallum irregularly ovoid, much depressed, broadly attached, and expanded laterally into a thin undulating somewhat foliaceous, but not everted, outer margin.

Wall horizontal, epitheca thick and rugose, with only feeble indications of costæ.

Calicular surface slightly convex, uneven; the fossula excentral, shallow, and slightly ovoid.

Septa rather irregular in thickness, not diminishing as they approach the fossula, and having indications of lobes rather than papillæ along their margins.

There are nine cycles and six systems.

The septa of the primary cycle meet and unite in the centre of the visceral space; those of the secondary are nearly as long as the primary; those of the third are a little shorter than those of the second, those of the fourth three fourths the length of the third, those of the fifth three fourths the length of the fourth; and they decrease in regular order, until the ninth cycle has septa which are one fourth the length of the primary ones.

Height of the corallum $\frac{1}{4}$ inch.

Greatest diameter of the calices 1 inch.

This species is remarkable for being depressed in form, and at the same time broadly attached. The discoid *Montlivaltiæ* are usually either free or attached by a small surface.

It was found by the Rev. P. B. Brodie, in the Middle Lias at Charmouth, in the bed which has been designated by Mr. Day the Star-fish bed*, and characterized by the presence of *Ophioderma Egertoni*. It has been very kindly lent by him for my use in this paper.

MONTLIVALTIA EXCAVATA, n. s.

Corallum regularly turbinate, broader than high, and attached.

Epitheca thick, and presenting rounded folds without any trace of costæ.

Calice symmetrically oval, very deep, and the calicular edge very thin.

Septa projecting to a very trifling extent into the visceral cavity. Their edges are smooth. There are six systems and five cycles. The primary septa pass down the inside of the cavity to near the centre, but do not become more prominent; the secondary ones are half the length of the primary, the tertiary ones two thirds the length of the secondary; and the fourth and fifth cycles are rudimentary.

The very regular turbinate and oval form of the corallum, the depth and openness of the calice, and the slight prominence of the septa will at once distinguish this species.

The five foregoing Middle-Lias species are rather remarkable for their difference from any hitherto recognized Liassic forms.

I had thought it probable that among the Middle-Lias corals of Normandy there might be some which would exhibit affinities with the species here described; but I do not find a single nearly affined form among those given by M. de Fromentel in his 'Paléontologie Française.'

MONTLIVALTIA ? TUBERCULATA, n. s. (Pl. IX. figs. 7 & 8.)

In an excavation made through the bottom of the Upper Lias into the marlstone at Adderbury, near Banbury, Mr. Kershaw and I met with two examples of a small sessile coral, which in size and regularity of form much resembles the *Trochocyathus Magnevillianus* of the Inferior Oolite of Dorsetshire.

The wall is thin, and the extreme upper margin free; the costæ rather indistinct, but thick, and corresponding with the septa. The calice is evenly and slightly convex, with a slight central

* Quart. Journ. Geol. Soc. August 1863.

depression. The septa are in six systems; and there are four cycles. They are thick, and their margins are fringed with tubercles. The centre of the calice is filled with a crowded mass of tubercles.

Diameter of the calice $\frac{3}{16}$ of an inch, height $\frac{1}{8}$ of an inch.

In weathered examples, in which the whole of the calice has been worn down, the central tubercular mass is still visible; but I have failed to distinguish the presence of the pali. The septa appear to lose themselves in the central mass, somewhat as they do in the genus *Cyathophyllia.*

I have seen about twenty specimens of these small corals referable to this species, all of which have been found in the lower part of the Upper Lias associated with *Ammonites Hollandrei.*

The excavation at Adderbury, from which several of these specimens have been taken, was made for the purpose of raising iron-ore from the marlstone of the Middle Lias, which is here overlain by a few layers of Upper Lias, in which the corals occur. *Ammonites Hollandrei*, with which they are associated, takes the place, in this district (as I learn from Mr. Beesley), of *Ammonites annulatus.* At King's Sutton, hard by, is another excavation into the marlstone; but it is without the overlying Upper Lias, and the beds are altogether a little lower in the series than those at Adderbury. The village of King's Sutton, though so near Banbury, is in Northamptonshire; but care must be taken not to confound the iron-works there with those in the Northampton Sands, which are in quite a different formation.

Appendix.

Since the foregoing was written I have examined some other Lias corals, one of which is certainly new.

A small discoid *Montlivaltia* from the coral zone at Fenny Compton was exhibited by Mr. Beesley at the meeting of the Warwickshire Naturalists' and Archæologists' Field Club in February last as *Montlivaltia radiata.* An examination has convinced me that it is quite distinct both from it and from *Montlivaltia nummiformis*, and that it is undoubtedly new. I describe it as

Montlivaltia papyracea, n. s. (Pl. IX. fig. 9.)

Corallum discoid, symmetrically round, extremely thin and delicate, and attached by the centre of its base.

Wall perfectly horizontal, flat; its extreme margin thin, free, and entire.

Epitheca thin, but very distinctly imbricated concentrically. No appearance of costæ.

Calice highest in the middle; septa straight and retaining their thickness as they approach the centre. They constitute five cycles. Those of the first, six in number, thicken a little toward the centre, where they meet but do not blend; those of the second approach nearly, but do not reach the centre; those of the third are three fourths the length of the second, and those of the fourth only half the length of the second. The fifth cycle is rudimentary.

Breadth $\frac{3}{4}$ inch, height $\frac{1}{8}$ inch.

The spines on the margin of the septa have been broken off; but their sides are ornamented with numerous minute papillæ. None of the septa extend laterally beyond the margin of the wall.

Besides Mr. Beesley's specimen, I have two ill-preserved fragments from the same locality, which I have hitherto regarded as examples of *Montlivaltia radiata*.

From Mr. E. A. Walford, of Banbury, I have also received a small collection of corals from the Middle and Upper Lias of the neighbourhood, submitted to me for identification. They are as follows:—

1. Thamnastræa Etheridgei.

A very perfect and beautiful specimen, having the calices so regular as to have led to the error of attributing the species to the genus *Isastræa*; but the columella, though not strongly developed, is present, and the septa of contiguous calices are confluent, and the corallum, though regularly convex superiorly, is more or less foliaceous and creeping laterally. But the existence of synapticulæ furnishes the most decisive evidence. From the marlstone of King's Sutton, Northamptonshire.

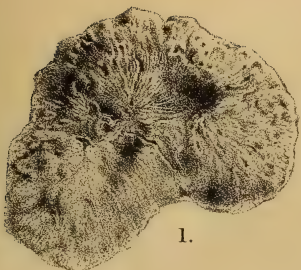
2. Montlivaltia tuberculata.

Three examples are forwarded by Mr. Walford, all from the same locality, Adderbury. They do not furnish additional information, excepting that, being all of one outward form and size, and similar in these respects to all the other specimens from the same locality, they may be taken as confirmatory of the full size and proportions of the species.

3. Thecocyathus Moorei? Edw. and Haime, Brit. Foss. Cor. p. 144, pl. xxx. fig. 6.

A single example, which has externally the appearance of this species, has been obtained from the Upper Lias in the railway-cutting at Eydon, nine miles north-east of Banbury, by Mr. Walford. Unfortunately, the calice is too much obscured to admit of an examination of the pali, which are very characteristic in this species. It was associated with *Ammonites Hollandrei*, and was probably in the lower part of the Upper Lias, whereas the Ilminster examples were found by Mr. Moore in the upper part.

In addition to the foregoing three species I have quite recently been favoured with several specimens of *Montlivaltia Guettardi* from the *A.-Bucklandi* zone of Redcar; and a careful comparison of these with *Montlivaltiæ* collected by myself at Pebworth has convinced me that they are specifically identical.



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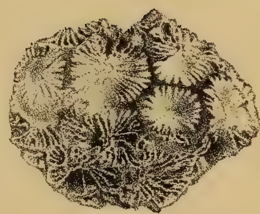

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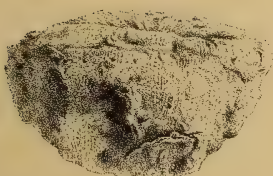

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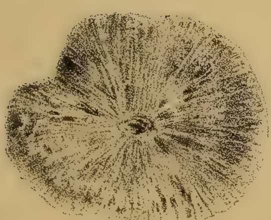

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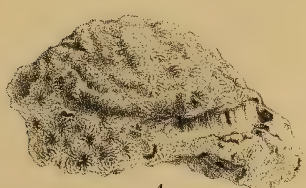

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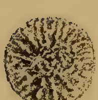

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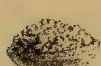


8.

9.

A. S. Foord. del. et lith.

Mintern Bros imp.

LIASSIC CORALS.

EXPLANATION OF PLATE IX.

Fig. 1. *Tricycloseris Anningi*, nat. size, showing the calicular surface
Fig. 2. *Cyclolites cupuliformis*, nat. size, showing the corallum.
Fig. 3. Calice of the same, nat. size.
Fig. 4. *Thamnastræa Etheridgei*, nat. size.
Fig. 5. *Thecosmilia socialis*, nat. size.
Fig. 6. The same, nat. size., showing the calicular surface
Fig. 7. *Montlivaltia tuberculata*, nat. size.
Fig. 8. The same, nat. size, showing the calice.
Fig. 9. *Montlivaltia papyracea*, nat. size, showing the calice
Fig. 10. *Montlivaltia foliacea*, nat. size.

17. *On some* Foraminifera *from* Pleistocene Beds *in* Ischia. By M. Ernest Vanden Broeck, Membre des Sociétés Malacologique et Géologique de Belgique &c. &c. *Preceded by some* Geological Remarks *by* Arthur Wm. Waters, Esq., F.G.S. (Read February 6, 1878.)

Stratigraphical Note.

Sir Charles Lyell, in the first edition of the 'Principles,' called attention to the fossiliferous deposits occurring at a considerable height in the Island of Ischia, near Naples, and containing shells which, with one exception, are the same as those now living in the Mediterranean. In each edition of both 'Elements' and 'Principles' they have also been mentioned, though somewhat less fully.

In this island there are fossiliferous deposits of three different ages, of which the Monte-Buceto clay occurring up to 1800 feet above the sea-level*, is the oldest, while the others should be classed with "raised beaches." As Sir Charles Lyell says†, "In Ischia I collected marine shells in beds of clay and tuff, not far from the summit of Epomeo or San Nichola, about 2000 feet above the level of the sea, as also at another locality, about 100 feet below, on the southern declivity of the mountain, and others not far above the town of Moropano. At Casamicciol and several places near the sea-shore, shells have been long observed in stratified tuff and clay. From these various points I obtained, during a short excursion in Ischia, 28 species of shells, all of which, with one exception, were identified by M. Deshayes with recent species." It seems uncertain whether the fossils given in his list were not collected from beds of various ages; and the list itself has given me that impression on a comparison with my own collection.

Sig. F. Fonseca‡ has given the following list of shells from the Buceto beds:—

Nassa prismatica,	Cassis undulata,
Solen coarctatus,	Turritella communis,
Rissoa polita,	Nucula sulcata,
Natica sordida,	Murex vaginatus,
—— Valenciennesii,	Fusus rostratus.

In a paper read to the Manchester Geological Society§, I added

* This is not caused by alteration of relative level of a wide area, as in the case of the Macclesfield and Moel-Tryfaen beds, but is the result of local movement, which has raised the whole of the island of Ischia, with Monte Epomeo in the centre, dipping at an angle of about 30° in an easterly direction.

† 'Principles of Geology,' by Charles Lyell, ed. 1, 1833, vol. iii. p. 126.

‡ Geologia dell' Isola d'Ischia, per F. Fonseca, 1870. Firenze.

§ "Remarks on the Recent Geology of Italy," Trans. Manchester Geol. Soc. vol. xiv. pt. xiii.

the following ten, which I collected from the Buceto beds at nearly 2000 feet above the sea-level.

Cardium ciliare, *Lam.*
—— echinatum, *L.*
—— edule, *L.*
Nassa Ascanias, *Brug.*
Rissoa cimex, *L.*
Trochus crenulatus, *Brocc.*
—— exasperatus, *Penn.*
Cerithium reticulatum, *Mont.*
Phasianella pulla, *L.*
Dentalium entalis, *L.*

All these species are now living in the sea of the neighbourhood, though *Nassa prismatica* and *Murex vaginatus* are rare; and the size seems to vary but little from that of recent specimens.

As the recent character of the shells which lived anterior to such great changes of configuration as have occurred in the neighbourhood is a fact of the highest importance, I thought that perhaps the Foraminifera might throw further light on the age of the deposit, and sent to my friend M. Vanden Broeck, of Brussels, some of the clays I brought from Ischia*. These, he found, did not contain any Foraminifera; but subsequently finding a few in the clay matrix of one of the fossils, I sent a pill-box full to Brussels, and received some most interesting remarks in a letter from M. Vanden Broeck, and with his permission communicate the following translation.

Note on the Forämininifera. By E. Vanden Broeck.

According to promise, I now send a list of the Foraminifera which I found in the last sample of marl you asked me examine. There were:—

Dentalina communis, *D'Orb.*
—— —— var. consobrina, *D'Orb.*
—— guttifera, *D'Orb.*
Lagena lævis, *Mont.*
—— marginata, *Mont.*
—— —— var. lucida, *Will.*
—— squamosa, *Mont.*
Bulimina pupoides, *D'Orb.*
—— aculeata, *D'Orb.*
Virgulina Schreibersii, *Czjzek.*
Bolivina punctata, *D'Orb.*
—— plicata, *D'Orb.*
Textularia pygmæa, *D'Orb.*
Verneuilina tricarinata, *D'Orb.*
—— spinulosa, *Reuss.*
Cassidulina lævigata, *D'Orb.*
Globigerina bulloides, *D'Orb.*
Discorbina globularis, *D'Orb.*
—— rosacea, *D'Orb.*
Planorbulina mediterranensis, *D'Orb.*
—— Haidingeri, *D'Orb.*
Truncatulina lobulata, *W. & J.*
Rotalia Beccarii, *Linné.*
—— nitida, *Will.*
Pulvinulina auricula, *F. & M.*
Nonionina depressula, *W. & J.*
—— scapha, *F. & M.*
Polystomella striato-punctata, *F. & M.*
—— crispa, *Linné.*

This small fauna has, without doubt, a more recent facies than that of the Subapennine deposits properly so called.

All the species from the marl are found now living either in the

* Costa has, in his 'Paleontologia del Regno di Napoli,' described a large number of Foraminifera from Casamicciola, which is of the same age as the Monte-Buceto clays; but he unfortunately gave nearly every species a new name, and entirely neglected the size; so that his lists of the fauna are not so useful as they otherwise would be. They, however, show the very recent nature of the deposit.

North Atlantic or in the Arctic Ocean. Almost all are also found living in the Mediterranean; but the presence of *Lagena*, of *Nonionina depressula,* and *Cassidulina lævigata* (which last does not appear really at home except in the colder waters of the North Atlantic, and is very rarely found in the Mediterranean) indicates closer relations with the Northern Oceanic fauna than with that of the warmer Mediterranean. The fauna of the Subapennines includes, besides *the greater part* of the species of our short list, a moderate proportion of extinct forms of special and characteristic species, of which no representative is here found.

With some exceptions, such as *Rotalia Beccarii*, these Foraminifera from Ischia are generally of small size, and appear to have lived in conditions but little favourable to their development. It is known that in the greater part of the Pliocene beds of Italy it is entirely different; the Foraminifera are there mostly large and very well developed; certain species in these beds are even remarkable for the size that they attain (*Nodosaria*, *Dentalina*, and *Cristellaria* for example).

Although the lithological nature of the deposit does not indicate littoral conditions, the depth of the water need not, however, have been very great; for we find among the Foraminifera of this marl most of the species that are generally found in littoral deposits of the existing seas. Such are specially the three *Lagenæ*, *Planorbulina mediterranensis*, *Truncatulina lobulata*, *Rotalia Beccarii*, the *Nonioninæ*, and the *Polystomellæ.*

To return to the marl of Monte Buceto, it is, without doubt, more recent than the true Subapennine deposits; and on the one hand the small size of the specimens, and on the other the predominance of certain northern forms, would seem to indicate a climate less favourable than that now enjoyed in the Mediterranean. Hence we are led to believe that the marl was deposited when the influence of the great refrigeration of the glaciers had begun to be felt.

18. *The* Precarboniferous Rocks *of* Charnwood Forest.—Part II. By the Rev. E. Hill, M.A., F.G.S., Fellow and Tutor of St. John's College, Cambridge, and the Rev. T. G. Bonney, M.A., F.G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read January 9, 1878.)

[Plate X.]

Contents.

The Microscopic Structure of the Charnwood Rocks.

In many cases the task of determining the nature and structure of these rocks is comparatively easy; but in others it presents great difficulties. These arise from the amount of metamorphism which the rocks have undergone since they were first deposited. This metamorphism may be said to be of a double nature:—the one, readily apprehended by the eye, that which has converted sandstone into quartzite, and fine felspathic detritus into something resembling a felspathic igneous rock, being in all probability the combined effect of pressure, heat, and water; the other, almost wholly revealed by the microscope, in which the last of the above-named agents of change has probably been the most active, and which may still be in progress—namely, the gradual decomposition of the minerals which once composed the rocks, and the formation of new ones by fresh combinations of the chemical elements thus set free. This process often obscures, far more than the former, the original structure of the rock; and it is this accordingly which causes our main difficulty in the study of these Charnwood rocks.

To investigate microscopically all the varieties of stratified rocks found in the Forest would be a most laborious task; and in all probability the result would not compensate for the labour. We have therefore selected a series of specimens which appeared either typical of the more important varieties, or likely to be useful in illustrating some point of structure or stratigraphy. Forty-four slides in all have been examined*, which may be thus classed—(1) Quartzites, (2) Slaty Rocks, (3) Coarser Fragmental Rocks, (4)

* Prepared very skilfully by Mr. F. G. Cuttell, of 52 New Compton-street Soho.

Highly altered Rocks, (5) Fragments from Breccias. Repeated comparisons have been made between the less and more highly altered varieties; and these again have been compared on the one hand with sections of volcanic breccia from the Tyrol and Scotland, and from the closely allied Borrowdale series of the Lake District, and on the other with a considerable collection of lavas, ancient and modern, from France, Germany, Italy, and Hungary. After the greater part of the work was completed a series of devitrified Pitchstones from the Wrekin was obtained, which was of great help in deciding some doubtful points.

(1) *Quartzites.*—Rocks mainly composed of indubitably rolled fragments of quartz are rare, as is shown in Part I., in the Forest, though grains of this mineral are, to a greater or less extent, present in several varieties. Of the latter, however, we shall speak further on; at present we restrict ourselves to those rocks which are evidently altered sandstones. Three sections have been examined—one from the Stable Quarry in Bradgate Park (p. 763*), another from the quarry near Steward's-Hay Spring (p. 769), and the third from near the Brande House (p. 760).

These rocks all consist mainly of rounded and subangular grains of tolerably clear quartz in a matrix of smaller quartz grains with black dust (? magnetite) and a green mineral, which, on examination, seems to be probably partly viridite, partly a chloritoid mineral. Besides the quartz there are a few other grains not easy to determine; some resemble a fine quartzite, some indurated slate, some lapilli.

In the Stable-Quarry specimen the quartz grains average about ·02 inch in diameter, and are not very clear †; the green mineral sometimes seems to penetrate a slight distance into them. In that from Steward's-Hay Spring the granules are smaller, a little more angular, and clearer, and the black mineral predominates over the green. In that from Brande House the grains are rather more irregular in form than in the first, and there are more fragments of other rocks, some certainly indurated slate. On the whole, microscopic examination renders it probable that these three beds are on the same horizon, as we have suggested in Part I. (p. 784).

(2) *Slaty Rocks.*—These are very abundant at various horizons in the Forest. As the structure of the roofing-slates does not seem exceptional, we have not examined them microscopically, but have selected one or two of the banded slates as likely to throw light upon the origin of the materials, and of the highly indurated compact slates in order to study their metamorphism.

Banded Slate near Ulverscroft Mill.—Felstone-like variety described in Part I. (p. 767). Ground-mass semitransparent, minutely granulated; darker parts earthy, and frequently showing a streaky structure; lighter parts apparently comminuted felspar crystals, in form

* These references throughout are to Part I. of this paper in vol. xxxiii. of this Journal.

† The numerous extremely minute dark microliths show an approach to a banded arrangement in the several grains.

roughly triangular or quadrangular; numerous larger felspar fragments, both orthoclase and plagioclase, fairly well preserved; seemingly a few lapilli, some showing minute plagioclase crystals; there are very abundant minute crystalline granules of epidote, besides larger crystals, also viridite in irregular filmy patches. The materials of this rock seem to be pyroclastic, not worn by, though perhaps deposited in, water.

Forest-Rock-Inn Quarry (p. 773).—Ground-mass similar to, but more uniform than last; little or no viridite; not much epidote, but a good many minute grains of some ferruginous mineral. So far as can be inferred from the form of the few larger felspar fragments, the materials of this rock are not obviously water-worn.

Slate from N.E. corner of Bradgate-House Woods (p. 787).—One of the finer little-cleaved pale-green slates; specimen collected about four feet from the syenite; ground-mass similar to, but yet finer and more altered than, the last; the more earthy part often in fine clotted granules; fragmental felspar crystals in bands, many of them almost wholly replaced by secondary microliths, bright-coloured with crossed Nicols; indications of minute lapilli, but less distinct than in the Ulverscroft specimen. Origin probably similar to that of the last rock.

Indurated Slate from south end of High Towers (p. 773).—A compact flinty rock of greenish-grey colour, with spots and streaks of a dark ferruginous mineral; in large fragments in an ashy breccia. The ground-mass is very finely granulated and rather earthy-looking; in it are irregular grains of felspar, seemingly fragments, in tolerably distinct bands. Origin probably as before.

Ashy Slate near Steward's-Hay Spring (p. 786).—A much softer-looking and less flinty rock than the last; syenite is intrusive in it. One specimen has been examined from near the northern junction with that rock and two from near the southern, one of these exhibiting actual contact; the ground-mass is finely granular, tinged slightly with viridite, with many opaque granules, and numerous felspar crystals of irregular shape and slightly banded arrangement; many of the larger granules resemble decomposing ilmenite; the form of the felspar crystals generally suggests plagioclase, but this has been replaced by an aggregate of rather fibrous microliths, bright-coloured with crossed Nicols. The longer diameters of the crystals in the junction specimen are roughly parallel and inclined to the bands; they are parallel to the surface; there is a little quartz, probably secondary; doubtful indications of included lapilli; the condition of the felspar crystals makes it very difficult to decide whether they are fragmental or of secondary formation; the ground-mass of the first-named specimen is the most highly altered, and it contains some ill-defined green crystals, possibly altered hornblende.

(3) *Coarser Fragmental Rocks.*—These rocks, though the size and nature of the included fragments vary considerably, may be thus generally described. In a ground-mass, consisting apparently of comminuted felspar more or less altered, and often streaky with a chloritoid mineral, are a number of larger angular fragments of

felspar crystals, both orthoclase and plagioclase, with lapilli and fragments of altered rocks, generally slates. The lapilli are unmistakably of igneous rock, irregular in form, doubtless volcanic; sometimes they resemble a glass, rendered more or less opaque by impurities (chiefly ferruginous), sometimes they are crowded with minute plagioclase crystals, and are doubtless andesite, sometimes they exhibit (with crossed Nicols) an imperfectly crystalline mosaic-like structure common in many trachytes*. Subangular, and sometimes rounded, fragments of quartz are present in many cases; grains of magnetite or ilmenite are frequently scattered about; viridite and epidote are often abundant as secondary products.

We proceed to indicate briefly the peculiarities of the various sections which we have examined.

Forest-Rock-Inn Grit (p. 773).—Much viridite in ground-mass; fragments mostly felspar, generally, as it seems, orthoclase; these contain numerous minute endomorphs, bright-coloured with crossed Nicols, doubtless decomposition products; some quartz fragments; a few doubtful, whether lapilli or altered rock. The rock is probably not pyroclastic.

Rock from Spinney north of Old John (p. 764).—Much fragmental felspar of both kinds, altered as above; a little quartz; lapilli of both kinds; also a few fragments of slate. A pyroclastic rock.

Bawdon-Castle Grit (p. 783).—Ground-mass largely composed of minute felspar crystals, in form resembling plagioclase; larger broken crystals of both kinds; lapilli, some the impure glass, some andesite, one or two showing plagioclase crystals very clearly; crossed prisms show a bright-coloured fibrous mineral with the viridite (possibly a variety of hornblende); a little quartz and not much epidote. A pyroclastic rock.

Grit-bed, summit of Broombriggs (p. 759).—A little finer than the last, and rather more altered, and with rather more quartz grains of irregular outline; lapilli less distinct, of trachytic aspect, but possibly, in some cases at least, only highly altered slate fragments.

There is a certain resemblance between these two rocks which may be significant, though it is hardly enough to enable us to class the former (of whose horizon we are ignorant) with the latter.

Grit from Quarry near Forest Gate, Loughborough (p. 755).—Ground-mass rather streaky, containing often much dark dust; many fragments; felspars of both kinds; rather clear quartz, subangular in form; and numerous lapilli, mostly andesitic; a few fragments of an indurated slaty rock.

Agglomerate near Woodhouse Mill (p. 759).—A pyroclastic rock as above. The lapilli appear to be mostly andesite; one contains six or seven very distinct plagioclase crystals, the largest about

* It is of course one of the forms of microcrystalline structure. We shall refer to fragments exhibiting it as "trachyte," because it occurs (as specimens from Hungary show) in trachytes of all kinds, but shall call those consisting of a glass crowded with minute plagioclase distinctively andesite.

·013 inch long, others glassy; ilmenite appears to be present as well as magnetite.

As stated in Part I. (p. 784), there are stratigraphic reasons for thinking these two rocks nearly on the same horizon, and the microscopic examination is not unfavourable to this correlation.

Markfield Breccia by Copt-Oak Road (p. 770).—Quartz grains are rare in this, and broken felspar crystals less common than usual. Some fragments of an altered slaty rock with lapilli of slaggy, trachytic, and andesitic rock, generally minutely crystalline, and so somewhat more difficult to distinguish than usual; still some fragments of the last cannot be mistaken.

Breccia from Old-John Hill (p. 764).—Ground-mass in parts very streaky; broken felspar crystals here also less common than usual, the majority plagioclase. Though this breccia contains huge fragments of slate, most of the smaller are lapilli, and these are mainly andesitic.

Breccia from Ulverscroft Mill (p. 767).—As in the last, felspar crystals are not very abundant; a small number of angular and subangular quartz grains; lapilli of andesite very abundant, some also trachytic, and a few perhaps are altered slate.

As stated in Part I. (p. 784) there is reason to think these three rocks about the same horizon. The microscopic examination, especially in the case of the first and second, is decidedly favourable to the correlation. The rock of the spinney north of Old John described above seems also very similar to them. Its position on the map shows it to be probably intermediate between these and the rocks described below, so that we may venture to include it also in horizon 2.

Timberwood Hill (p. 772).—The ground-mass is variable and streaky; there are the usual felspar crystals and occasional quartz grains; undoubted lapilli are rare; one rather large fragment is more like a clastic mass of small felspar crystals (*i. e.* a fragment of an ash) than a true igneous rock. One fragment of quartz appears to have split up into several pieces, between which the ground-mass has made its way.

Green Hill, Woodhouse (p. 766).—Rather similar to the last, but there is more subangular quartz, and the lapilli are more distinctly marked, mostly not definitely andesitic. A large pinkish fragment, included in the slide, shows the trachytic structure.

Barnby Wood (p. 771).—The lapilli are still more distinctly marked than in the last, and of the same character.

Agglomerate under Slate near Cottages east of Monastery (p. 776).—Felspars as usual; lapilli rather numerous, some certainly andesitic, one, besides plagioclase, showing a little hornblende, crystals black-bordered*; quartz grains rather numerous; some ilmenite of fair size, and viridite as usual.

Coarse Agglomerate, Kite Hill (p. 775).—Felspar a good deal de-

* Said by Zirkel (Report of Geol. Expl. of 40th Par. U.S.A. vol. vi. p. 94) to be very characteristic of the hornblendes of andesites and trachytes. Doubting whether the black mineral is magnetite, he calls it provisionally opacite.

composed; several grains of quartz; presence of lapilli uncertain; rest much as usual.

Benscliff Agglomerate (p. 765).—Here also the lapilli are less distinct than usual, and there is rather less epidote; quartz grains &c. as usual.

Matrix of Whitwick Breccia (p. 779).—A finely comminuted felspathic ground-mass, rather similar to, but more uniform than, those above described, speckled with minute ferruginous granules; viridite and epidote rather abundant, the latter often aggregated.

Of the last seven rocks there is reason to think, as already stated, that the first six belong to the same group, though not necessarily to exactly the same horizons in it. Microscopic examination reveals nothing opposed to this, and shows that the Kite-Hill, Benscliff, and Timberwood-Hill rocks have a close resemblance. The Green-Hill and Barnby-Wood rocks differ somewhat, and the Monastery rock is distinguished by distinctly andesitic fragments. The Whitwick rock may be allied to the first three, but there is little positive evidence.

From these numerous instances we seem to be justified in drawing the following conclusions:—

(*a*) That these coarser Charnwood rocks are generally pyroclastic.

(*b*) That they contain numerous lapilli still easily recognizable.

(*c*) That the majority of these belong to one of the more acid plagioclase lavas, probably andesite.

(*d*) That the larger felspar crystals are of clastic origin, and not subsequently formed by metamorphism of the ground-mass.

(*e*) That the quartz also is of clastic origin.

(4) *Highly altered Rock, Ratchet Hill* (p. 777).—We may take this as typical of the highly altered felspathic rocks common in the N.W. district of Charnwood Forest. They have a compact, slightly porphyritic ground-mass of a purplish-grey colour, and a rather flaky aspect, due to imperfect cleavage. The ground-mass of the slide is partially translucent, but thickly crowded with minute brownish granules irregularly aggregated. With crossed Nicols it shows a dark base crowded with very minute transparent belonites not clearly defined; grains of magnetite or ilmenite are present, more or less decomposed; patches of viridite often studded with aggregated crystals of yellow epidote, which mineral is also found minutely disseminated; a chloritoid mineral is also present; the outline of these patches of viridite and epidote suggests that they are secondary products after some such mineral as augite or hornblende. It would not be safe to say more than that this rock is of clastic origin.

Peldar-Tor Rock (p. 776).—This remarkable rock has a compact felstone-like greenish- to purplish-grey ground-mass, crowded with ill-defined, rather pale red, lustreless felspar crystals, and numerous grains of quartz, often showing imperfect crystal faces. The felspar crystals are generally squarish in form, attaining full 0·3 inch in diameter, about the same as the quartz grains. Under the microscope the ground-mass is rather variable. It resembles a transparent glass more or less crowded with exceedingly minute dusty brown microliths (and ? cavities). A faint green tinge runs through this, like a kind of network, so that the field seems to be occupied by a number of rather ill-defined roundish grains set in a duskier and greener base; sometimes these almost disappear and the ground-mass becomes rather streaky. With crossed Nicols the ground-mass rather resembles the last, only the doubly refracting portions are less clearly defined. Many of the rounded patches disappear, giving it a more streaky aspect, while those which remain become more definite and angular in outline. Dusty clusters and dark grains with grouped epidote are scattered about. The larger felspar crystals are greatly decomposed, being sometimes almost wholly replaced by epidote and viridite or by a zeolite*; still there are indications that these are of clastic origin. Both kinds of felspar seem to have been present; this is confirmed by the smaller crystals, which, strange to say, have escaped better. The quartz grains vary much in size and form, some being less than ·01 inch in diameter; generally they are roundish, but some are distinctly subangular and irregular in form, one strip, which is incomplete, being quite 0·15 inch long; it is broken through three or four times. Sometimes these grains are separated from the ground-mass by a sharp line of division; but more frequently it seems to melt rapidly into the quartz, so that the latter is surrounded by a finely granulated band about ·001 inch wide. Both modes of limitation may occasionally be seen in the same specimen. The quartz grains show bright colours, are sometimes clear, and sometimes contain small dark microliths and cavities. The question of their origin, and that of the felspar crystals, will be discussed hereafter. There are one or two grains of a translucent pale green mineral, with the edges and cracks (the latter sometimes crossing one another roughly at right angles) defined by thickly clustering black granules. The clear part contains many small pore-like cavities, some apparently empty, others stained with black. With polarized light the green, as before, appears to be an aggregate of a chloritoid mineral. In general appearance this mineral rather recalls the structure of olivine or garnet, and may be a pseudomorph after one of these.

Bardon Hill, Porphyritic Rock of Lower Quarry, north side (p. 781).—In microscopic structure this rock is extremely similar to the last; but the quartz grains (which are often a little longer) approach nearer to crystals in outline, and are traversed by some large and very many minute cracks, the latter frequently meeting nearly at right angles. The quartz contains some rounded patches of viridite enclosing clusters of minute epidote. One or two grains of the green and black mineral mentioned above are present. On the whole the microscopic evidence for the identity of these two rocks is very strong.

Bardon Hill, Lower Quarry, south side (p. 781).—We have already (*loc. cit.*) described the remarkable change in this rock as it is traced

* For brevity we will thus designate the secondary microliths, already mentioned (p. 201), the precise nature of which we have not yet been able to determine. We suspect the mineral to be orthorhombic.

across the quarry; that it is indeed considerable is proved by microscopic examination. The ground-mass of this rock resembles generally, in its minuter structure, both those last described, but is more streaky, showing the rounded granules both more rarely and less distinctly. With crossed Nicols the difference is more marked—a considerable portion of the ground-mass remaining dark, but being crowded by minute, ill-defined, clear spots, and many small felspar crystals, resembling fragments, many of these being long and narrow, like clippings of thread. Thus, at first sight, the ground-mass much resembles that of an igneous rock; but closer inspection shows that the granules vary rather more in form and size, and the felspar microliths are more ragged at the edge than is usual in lavas. The same minerals as in the above-named rocks occur porphyritically; but the felspar crystals are rather better preserved, though some are almost replaced by epidote, which shows remarkably beautiful colours; the edges of others have a fractured aspect. The quartz grains are reduced in size and still more in number.

Bardon Hill, Compact Rock of Upper Pit (p. 781).—This rock is of a greenish or greenish-grey colour, indistinctly mottled, showing small glancing felspar crystals, and resembling a rather compact felsite. Under the microscope it has a general similarity to the rock last described, except that the felspar crystals (apparently of both kinds) are smaller and more altered, and the abundance of minute epidote, intercrystallized with earthy granules, rather obscures its structure.

Birchwood Plantation (p. 771).—This rock has considerable resemblance to the last described, and the microscope shows it also to have undergone great alteration. There is the usual clear glassy base, with dusky granulations, which here and there seems to indicate the former presence of fragments by their aggregation in irregular lines. Although on crossing the Nicols the slide, as a whole, shows an imperfectly crystalline structure, which might belong to some lavas, yet here and there, in the apparent fragments, there is a marked difference, such as long acicular crystals, instead of the more irregular forms. Larger felspar crystals are present, apparently of both kinds (much altered in the usual way), with a little fibrous hornblende (?) and still less quartz. On the whole it is more probable that this is only an altered rock; and this is quite in accordance with its appearance in the field. All the rocks of this group so closely simulate the structure of an igneous rock, and have been so much altered, that it is very difficult to recognize their true character. We believe, however, that careful study, both in the field and with the microscope, will prove they are of clastic origin, though probably volcanic materials have entered largely into their composition.

(5) *Fragments included in Breccias.*—In the north-western portion of the Forest (coloured on the Survey Map as a felspathic porphyry passing into altered Cambrian strata) breccias are numerous, as described in our former paper (pp. 772–779). Two kinds of rocks are there stated to be abundant, both resembling felstones—one a com-

pact purplish rock with whitish felspar crystals, the other a light greyish red with pale green spots. A rock much resembling the former occurs in the middle part of Bardon-Hill Quarry, and one resembling the latter is common in the upper breccias of the same place.

(A) *Purple Porphyritic Rock.*—The following specimens of this rock have been examined:—

Ratchet Hill (p. 777).—With transmitted light the ground-mass appears a tolerably clear glass full of minute black granules and trichites; there are occasionally small spaces clear of the granules, like ill-defined felspar crystals, larger microliths of magnetite, larger felspar crystals and grains of quartz, with a little epidote, and occasionally viridite. With crossed Nicols most of the ground-mass remains dark, but is crowded with small clear specks and long narrow felspar crystals. The larger felspar crystals show both orthoclase and plagioclase fairly well preserved; some have a rather broken outline, others a sharp linear boundary; one or two quartz grains show an approach to a crystalline form; microliths and small portions of ground-mass are occasionally included. A fragment analyzed under the superintendence of Prof. Liveing gave, according to one observer, $Si\,O_2 = 77{\cdot}6$; according to another, $= 77{\cdot}9$.

Fragment from south of Peldar Tor (p. 775).—This rock has a general resemblance to the last, except that the microliths are rather more definitely aggregated, giving the slide a more granulated structure. With crossed Nicols, however, many of the granules disappear, and the rock resembles the last, except that minute acicular felspar is more distinct; several of the granules prove, by rotating the prisms, to be minute spherulites. The same minerals are present porphyritically as in the last, but they are not quite so numerous.

Breccia, Bardon Hill, Upper Quarry.—This rock so closely resembles the last that a detailed description is unnecessary; the larger felspar crystals, however, are decidedly more numerous, and there is little or no free quartz, but more viridite and epidote. Its structure seems to justify the correlation suggested in Part I. (p. 782).

Though the microscopic structure of the above rocks differs a little from that of any recent igneous rock which we have hitherto seen, it corresponds rather closely with that of both some quartz-trachytes and some quartz-andesites from Hungary, so that they are doubtless either rhyolites or belong to that large class of trachytes intermediate between typical rhyolites and dacites. They correspond very closely in the structure of the ground-mass with some of the devitrified pitchstones from the Wrekin.

(B) *Pinkish Felsitic Fragments in Breccias.*—The following specimens of this rock have been examined:—

From Middle Exposure, High Towers (p. 774).—Ground-mass of this slide seems to be a glass full of granular earthy dust. Crossing the Nicols shows the glass to be partly devitrified, with many bright microliths in the dust, probably epidote, which is also abundant in larger crystals. Felspar crystals are numerous, but so much altered by the formation of secondary minerals that it is not safe to conjecture their origin.

Breccia, Bardon Hill, Upper Quarry (p. 781).—The slide shows a good deal of epidote, both in microliths and larger crystals, and a quantity of an earthy-looking granular dust; but on crossing Nicols an imperfectly crystalline ground-mass is seen, the bright patches being of irregular outline and form. Still the structure can be paralleled in some of the Hungarian trachytes; so that this rock also may be of igneous origin. There are occasional larger felspar crystals, but these are more or less replaced by epidote.

Breccia near Summit of Bardon Hill (p. 781).—This rock is rather similar to the last, except that it is more porphyritic, and the dusky granules are irregularly gathered together, so as to give it a fragmentary aspect. This, however, to a great extent, disappears on crossing prisms, and this rock too may be of igneous origin. It is doubtless difficult (owing to the extent of secondary metamorphism) to be quite certain of the origin of these fragments, but they are most probably devitrified quartzless orthoclase-oligoclase trachytes. The correspondence of the High-Towers specimen with those from Bardon, strengthens the reasons for referring the rocks of the latter to some part of the former series. A rather similar fragment from the agglomerate of Ratchet Hill is distinctly quartziferous, and contains, according to one analysis, $Si\,O_2 = 78{\cdot}9$; according to another, $Si\,O_2 = 79{\cdot}1$. These were kindly made by Mr. Houghton, Scholar of St. John's College. Its difference from the associated darker fragments (described above) is accordingly not very great, being chiefly in crystalline condition.

Breccia of Whitwick (p. 779).—Fragments of a pinkish to purplish rock of rather mottled aspect are common in this breccia; three of these have been examined. In two of them oval or lenticular patches, whose texture sometimes differs a little from the rest, are outlined by rather closer rings of darker granules, the ground-mass being composed of very minute microliths irregular in form and disposition, and brown or black dust, in an apparently glassy base.

These rings with crossed Nicols are seen to be associated with the bright hornblendic mineral already mentioned. On applying a selenite plate the above distinction is often made more clear, the colours within and without the mass being complementary. The longer axes of these spots are roughly parallel, indicating probably an imperfectly cleaved structure of the rock. The third fragment seems to show a similar structure; but has been more highly affected by secondary metamorphism, epidote, viridite, &c. being largely present. These rocks, on the whole, recall to mind the texture of the slates already described rather than that of true igneous rocks, but it is difficult to form any certain conclusion.

It now remains to discuss the origin of the larger felspar crystals present in many of the above rocks, and of the less frequent quartz-grains. The evidence on both these points is conflicting, and it is very difficult to arrive at a conclusion. The various slides have been studied comparatively, from the less to the more highly altered; and these again have been constantly compared with rocks, containing the above minerals, of undoubtedly clastic character on the one hand, and undoubtedly igneous origin on the other. Taking the case of the felspar first, and confining ourselves to the better-preserved examples, it is not easy to come to a conclusion—the fact being that it is very difficult to obtain critical characteristics. As a rule, in igneous rocks with a glassy or microcrystalline ground-mass, the porphyritic felspar crystals are rectilinear in outline; but still rounded, apparently worn, and even broken crystals are not rare; sometimes also the development of a crystal appears to have been arrested, so that its outline is indefinite and irregular. Of course the frequent inclusion of portions of the matrix in the crystals would be an evidence that they were formed in place; but one cannot argue from its absence. Now to take a few examples from those described above. In such rocks as the banded slates from near Ulverscroft Mill and Bradgate-House Wood (north-east corner) we can hardly doubt, seeing that there is no proof of extreme metamorphism in their structure, that the included felspar crystals in the coarser bands are of clastic origin; so also in the comparatively little altered rock from Forest-Gate quarry. But from this we pass readily to the grit of Bawdon Castle and the Woodhouse-Mill rock, and so to the more altered rocks from near the Monastery and Benscliff, from which the transition to the Peldar-Tor and Bardon-Hill rock is not very great. We might further expect that if the rock had been so greatly altered as to allow the formation of crystals, often one third of an inch in diameter, from the base, the latter must have been brought so nearly to a fluid state as to obliterate all trace of its original finer structure, as in the case of the crystallized felspar and mica in a gneiss, where the original constituents have to a large extent entered into fresh combinations, and the new minerals chiefly record the prevalence of the required constituents in those localities. But yet, in the great majority of these Charnwood rocks, we can distinctly make out the general nature of the ground-mass and the included volcanic fragments, with their characteristic structure; and even in the Bardon and Birchwood slides the ground-mass has not acquired a structure quite resembling that of a true felspathic igneous rock, and in one or two cases gives indications of having once been not perfectly homogeneous. Further, we find that in many much less ancient volcanic ashes broken crystals are largely mixed up with the scoriaceous fragments and amorphous dust—as felspar in the porphyrite tuff of Carlton Hill, Edinburgh; leucite in the tuff of Rome; augite and leucite in the peperino of Albano*. We find also that these crystals occur both in minuter powder and in larger fragments, so that there is no antecedent improbability in those which we have described in these old rocks

* With which compare some of the augitic or uralitic agglomerate of Rhobell Fawr (N. Wales). Fragments of felspar crystals are also abundant in an indurated basaltic ash from Caprile (Italian Tyrol), and augite crystals occur among the finer scoria of the Puy Noir (Auvergne).

being also of pyroclastic origin. Further, seeing that the ground-mass is evidently felspathic, and apparently often to a large extent consists of comminuted felspar, should we not expect that it would be the first to lose its characteristic structure, and that it would have to be quite melted before the larger fragments would be more than slightly affected? One does not of course forget the cases of crystalline and even porphyritic structure in gneiss and many schists; but then the alteration even in the most highly altered of these Charnwood rocks is far short of what has been undergone by the latter. Hence in the great majority of these Charnwood rocks it seems, on the whole, more probable that the larger, and even most of the smaller, felspar crystals are of clastic, and in many of pyroclastic origin; and so, by analogy, we incline, though more hesitatingly, to the same origin for that in even the coarsely porphyritic rocks of Peldar Tor and Bardon Hill.

Next, with regard to the quartz grains. We may unhesitatingly regard those of the grit of Steward's Hay, Bradgate-Stable quarry, and Forest-Rock-Inn Spinney as of clastic origin. Following the same method of investigation, we find that in igneous rocks (where the quartz is not in crystals) the mineral is generally of a roundish form, often seems to melt at its edge into the ground-mass, and contains portions of the same. Now in the Peldar-Tor and the Bardon rock the large size of the quartz grains, and the approach to crystal shape, certainly favours the idea of their having formed *in situ*; they sometimes melt into the ground-mass, and occasionally are pierced by, or even seem to contain small portions of it, especially the smaller granules. But then, just as with the felspar, we can proceed from the above grits, through such examples as the Forest-Gate, Bawdon-Castle, Broombriggs, and then the Monastery and Benscliff rocks, to the Peldar-Tor and Bardon-Hill rocks. Also we sometimes find subangular quartz fragments in true igneous rocks, such as trachytes and some felsites; and, on the other hand, in the above grits there is more than once a distinct tendency to a fusion of the quartz grains with the adjoining matrix*. Further, we can hardly suppose that such large grains as are found in the Peldar and Bardon rock could have been formed without complete fusion and recrystallization of the finer ground-mass, and this does not appear to have happened†. Here also, though with more hesitation in the case of some of the smaller round grains, we consider the quartz of clastic origin, in even the last-named instances. The grains are extremely like those in the fragments of the breccias of Ratchet Hill &c., though of smaller size, and like those in some trachytic lavas. Thus they might be produced by the explosive destruction of a quartz-trachyte. The leucite crystals of the Roman

* In the Monastery rock, where the general original structure is well preserved, the quartz grains may be paralleled now with those of the grits, now with those of Peldar Tor.

† There is not a trace of aggregate crystallization in these grains, which seems unfavourable to the idea of their filling cavities. They *might* possibly be pseudomorphs; but of what?

tuff can hardly have been otherwise produced, yet this is a more fragile mineral. Slides of the agglomerates from the Queen's Drive, Arthur's Seat, show quartz grains extremely like some of those in the Charnwood rocks. These can hardly be other than fragmental, for the rock is not highly altered. The whole structure indeed recalls that of some of the Charnwood rocks. A slide of basaltic agglomerate from a rock at Elie, Fife, even shows several small quartz grains almost certainly clastic.

It may perhaps be felt that the absence of lava-flows is a difficulty in claiming a pyroclastic origin for so many of these beds. It is doubtless a difficulty, but not without some parallel. Mr. Clifton Ward's map of the Borrowdale region (and whoever has had the pleasure of seeing him at work knows that he is not likely to have overlooked any thing important) shows that there the proportion of the lava-streams to the ash-beds is very small, and in the Charnwood area exposures are less extensive, and continuous sections far less frequent than in the Lake-district. Again, in parts of the Eifel also there is but little lava, and in the Phlegræan fields extremely little. The rarity of conglomerate, grits, and rounded detrital materials seems to indicate the absence of either rivers or tidal currents. Such a district, then, as the Phlegræan fields, consisting of many low craters, from which steam and ashes were discharged, standing near lakes or lagoons, would seem to supply the condition required for the formation of these Charnwood rocks. The lowness of the hills and porosity of their materials would be unfavourable to rivers; the ash would settle down in quiet waters, little rolled, or be spread out upon the plain. The land, owing to the frequent showers of ash, might be unfavourable to vegetation, and the volcanic disturbances might render the waters unprolific.

The Igneous Rocks of Charnwood Forest.

(1) *Preliminary.*—The true igneous rocks of the Charnwood-Forest area may, for convenience of description, be arranged under four heads. These are (*a*) the Southern Syenites, (*b*) the Northern Syenites, (*c*) the Granites of the Quorndon district, (*d*) the Later Intrusive Rocks. As is well known, some authors have expressed doubts as to whether the first three of these might not be highly metamorphic sedimentary rocks. Now in speaking of igneous and metamorphic rocks we must, of course, understand distinctly in what sense we use the terms. It is doubtless conceivable that a sedimentary rock might be melted down *in situ* by hydrothermal action, and recrystallized so as to be undistinguishable from a molten mass which has been forced upwards from the interior of the earth. Several instances of this have indeed been adduced; but the evidence on examination often proves defective, as one of the present authors has more than once ascertained. Further, if a rock were thus melted *in situ*, it might by earth movements be squeezed from its original position into a new one. In this case its demeanour would be identical with that of a true igneous rock; but then, as all trace

of its earlier history has been destroyed, there is no reason why it should not be called an igneous rock. We speak of a pig of iron as cast iron equally whether it has been just melted from the ore or from the fragments of an ancient railing. If, then, the term igneous rock be used to denote a rock which has been either poured out on the surface, like a lava-stream, or injected among other rocks (the only intelligible sense, as we contend), it has always appeared to us there was never any real ground for doubting the igneous origin of these Charnwood rocks. The evidence adduced against it was of the slightest kind—little more than a supposed transition from these rocks to the adjacent metamorphic sedimentary rocks, and an appearance of bedded structure. The supposed "transition" has always turned out on examination to be merely superficial resemblance; the "bedded structure" is only that tendency to parallel jointing which is not rare in large masses of igneous rock. Finally, the discovery of actual intrusive junctions, as already described, may be regarded as setting the question at rest. Owing to the character of the ground these are rare; but there are three good instances at least in the southern area, and three not quite so easily recognized in the northern.

The Southern Syenites.—A considerable area (see Map, Pl. X.) is occupied by these rocks in the vicinity of Groby, where they also form the southernmost exposures of the Pre-Triassic rocks of the Forest. Here they occur in insular masses, the summits of an ancient undulating district on which the Trias was deposited. Excellent sections of the irregular junctions of the two rocks, of the old weather-worn surface of the former, of the sloping stratification and included syenite boulders of the latter, are obtained in the great stone-quarries. There is little doubt that all these syenite masses are continuous beneath the surface, and that there is a tract extending from the village of Groby, for full two miles at least, in a north-west direction, the breadth generally being nearly three quarters of a mile. The presence, however, of slate and grit near Steward's Hay, on the east side of the Ashby road, shows that the south-western boundary of this patch is greatly incurved. Separated by a broad plateau of Trias is the great *massif* of Bradgate Park, which ends in the immediate vicinity of the ruins. We think this may fairly be regarded as continuous with the former, though the position of the slate north-east of Bradgate House shows that the north-western boundary is also incurved considerably. How far these *massifs* may extend to the south-east we have no means of knowing, except that the position of the Stable-Quarry Grit in Bradgate Park seems to indicate that we are there upon its eastern limit. North-west of the end of the Groby *massif*, separated by about three quarters of a mile of upland Trias, comes the Markfield exposure, a circular patch of syenite forming a commanding hill, and limited on the northern side by the slaty, on the southern by the Triassic rocks. Still in in the same direction, and across a broad, rather deep valley, apparently in the Trias, comes the Cliff-Hill syenite, forming also a conspicuous rugged ridge, probably a continuation of the former.

West of this, across nearly a mile of much obscured country, apparently slaty rock and Trias, is the Stanton-Field syenite, a patch on the Geological Map covering three or four square furlongs. But at the present time boulders scattered in the soil are the only evidence of its existence, so that we can give no particulars concerning this outcrop. These *massifs* then, if they are not connected, lie on a rude L-shaped area. Forming another hill, almost due north of Markfield, and about 1¼ mile from it, we have another *massif*, that of Hammercliff, on the edge of the Triassic valley.

The Northern Syenites.—Still further north, and nearly a mile away, is the interesting patch at Bawdon Castle. This, in the Geological Map, is coloured red as "syenite," all that which remains to the north being tinted crimson as "greenstone." As will be seen below, its relation to both these rocks is of much interest. The remaining "greenstones" form a series of rather narrow patches, four in number (two of which are apparently isolated in the slate), extending for about 1¼ mile in a north-west direction, and commencing about a mile to the north of the Bawdon-Castle exposure. One more patch there is, that of Great Buck Hill, about a mile east of the lower end of the above. As it will be seen that all these rocks are closely related, and that they are at least 2½ miles away from the nearest point of the Quorndon district, it will be convenient to complete the description of them before proceeding further.

(2) *Details of the Southern Syenite.*—The Southern Syenite is largely worked near Groby. The old pit lies south of the main road leading through the village, and is an excavation of great size. The syenite has all the appearance of a deep-seated igneous rock; it is traversed by bold joints, the faces of which often exhibit slickensides, especially along one plane, dipping at about 30°. The normal rock is rather coarsely crystalline, showing to the eye dark green hornblende with pink and greenish felspar, the latter being of rather dull aspect. Specks and nests of bright yellow-green epidote are not unfrequent, with occasional grains of pyrite. The joint-faces have commonly a brown ferruginous coating, and sometimes one of epidote. There is also found a much more finely crystalline variety of syenite. In this the red colour predominates, the green being chiefly confined to the hornblende, which either occurs in dark specks throughout the mass, as in one variety, or collected in fair-sized patches. Crystals of plagioclase felspar seem to be more common in this than in the other variety. We were told that the change from the one rock to the other was often rather rapid, and that neither seemed to be restricted to any particular part of the pit. There are in this pit two or three dykes of intrusive greenstone, which will be described hereafter. A cutting passing under the high road, and giving an excellent section of the Keuper sloping gently away from the above mass of syenite with a deposition dip, leads into another large pit in the mass east of Groby Pool. The rock here is so similar to that in the last pit, both varieties occurring, that no further description need be given. We have not seen any dykes here. In a disused quarry near is a quartz vein, which can

be traced some fifty yards. We have several times observed considerable portions of the old surface of the syenite exposed near here; it is very irregular, the projections being slightly rounded, but not so as to suggest glacial action. The Sheet-Hedges-Wood pit is a large excavation further north in the same mass; both varieties of the rock are found here, and the differences, if any, are so slight that no description is needed. There is a small greenstone dyke in this pit. The general character of the syenite all over this district, and in the hill at Markfield, where there are large excavations, is so similar that details would be only repetition; possibly an experienced quarryman might recognize the rock of his own pit, but in many cases we certainly could not undertake it. We have not, however, observed the finer variety of the syenite at Markfield, but have seen it in Bradgate Park, in the stream a little below the lowest fishpond, near to which there is also a greenstone dyke. In one of the Markfield pits there used to be a considerable vein of reddish calcite.

At the southern end of the Cliff Hill mass a large pit is worked. The texture of the rock is very like that of Markfield, but it has a slightly more decomposed aspect. There is more of the greenish-coloured felspar, and the red of the rest is paler. We did not see any dykes in this pit.

The rock is not quarried at Hammercliff, and so it is more difficult to obtain good specimens. In general it appears to be a little more finely crystalline than at Markfield, with a duller aspect, and an approach to the less definite crystalline structure which characterizes the northern syenites. A rather compact variety, of a tolerably uniform dull-green colour, is also found here.

Microscopic Structure of the Southern Syenite.—Slices of the coarser variety of this rock have been examined from the Old Quarry and the Pool Quarry, Groby, from Markfield, Bradgate-House Wood, and Cliff Hill. They resemble one another so closely that a detailed description of each is needless. The rock consists of felspar, hornblende, quartz, apatite, and oxide of iron, with various secondary products, as epidote, viridite, and chlorite. The felspar chiefly occurs in tolerably regular crystals, polygonal in section, approaching oblongs; there is a fair quantity of plagioclase as well as orthoclase. The former exhibits the usual parallel structure and sometimes zonal banding*. The felspar is often much decomposed, partly filled with brown dust, partly with minute granules. With crossed Nicols the

* MM. Poussin and Renard observe this structure in the oligoclase of the Quenast diorite (Mém. sur les roches plutoniennes, &c. p. 29); probably the felspar here also is oligoclase. A specimen of the Quenast rock, kindly given to me by Prof. Morris while this paper was passing through the press, has a general resemblance to that from Garendon (p. 217), except that it is lighter in colour and free quartz is conspicuous. Microscopic examination shows it to be nearer to the Narborough or Enderby rocks described below, the ground-mass being microcrystalline. It is, however, closely related lithologically to our Charnwood group of igneous rocks. This is remarkable, because Prof. Renard, in examining my collection of the more altered sedimentary rocks, was struck with their close resemblance to some of the "porphyroids" of the Ardennes.—T. G. B.

browner dust remains opaque; the more transparent granules appear to be sometimes of rather vermiform aspect, showing clear bright colours, pinkish, bluish, and yellowish, probably prehnite or some allied mineral. The exterior rim of the crystal often seems to have escaped better than the interior, or, as there is reason to think, pseudomorphism is here more complete on the exterior*. In some of the crystals a minute chloritoid mineral is also present. Separate grains of quartz, such as are seen in granite, are rare, but a good deal occurs intercrystallized with felspar in a very curious way. This structure, which was noticed by Mr. Sorby in 1863†, resembles "a microscopic graphic granite or hebraic felspar." The felspar is generally much decomposed, and occasionally stained green with chlorite; it sometimes occupies irregular polygonal spaces among the quartz, sometimes is more irregular and wavy in outline, presenting, when green, a rough resemblance to an alga. The quartz (with crossing Nicols) is uniform in colour over a considerable portion of this structure, showing that it forms a kind of composite crystal. Some examples rather favour the idea of this graphic structure being of secondary formation; but the evidence, on the whole, makes for its being original. The hornblende appears generally to be rather decomposed, is irregular in outline, often rather fibrous in structure, especially at the end; it is commonly partly replaced by viridite and epidote; some of it also looks like a pseudomorph after biotite; the iron is probably in the form of magnetite, but the mode of decomposition of occasional grains suggests ilmenite. The apatite occurs in clear, long, six-sided prisms, and is rather abundant in the Groby rock, especially in the slide from the Pool Pit, where some of the prisms are about ·045 inch long. It appears to have crystallized first in order.

The Cliff-Hill rock is a little more decomposed than the others, as we should expect from its appearance—fibrous zeolite, chlorite, and epidote abounding in place of the felspar and some of the hornblende. The latter mineral, however, has commonly a very unusual aspect, being fairly well preserved, with one well-defined set of cleavage-planes often marked out by minute included microliths, dichroism imperceptible when unaltered, and colour bright with crossed prisms. In fact the mineral much more resembles a diallage, and sometimes even augite, which in places is converted into uralite, actinolite, or viridite (the anisotropic variety); one crystal is twinned with the sections of the cleavage-planes at about 74° to the plane of twinning.

* In examining felspars in rather decomposed rocks, such as the Carboniferous dolerites of Scotland, I have often observed that a felspar seems to pass through the kaolinized stage to a clear pseudomorph, which shows only milky white and blue-black colours with the Nicols, instead of tints common with felspar.—T. G. B.

† Geol. Mag. vol. ii. p. 448 (from Geol. & Polyt. Soc. of Yorkshire). The rock here described is said to be from Mount Sorrel; but Mr. Harrison has ascertained (Geology of Leicestershire, p. 11) that the specimen came from Groby. Mr. Sorby calls attention to the fluid cavities in the quartz, which indicate that the rock crystallized under great pressure.

A specimen of the more compact syenite has been examined from the Sheet-Hedges-Wood pit. A good deal of the slide consists of intercrystallized felspar and quartz, the former rather predominating, with occasional rather large crystals, forming a mosaic of angular pieces, and passing into the graphic state. There is some hornblende, more or less decomposed, irregular in shape and distribution, with epidote and viridite, as usual. The felspar is considerably decomposed, and occasionally quite replaced by the usual zeolite; but enough remains to show that both orthoclase and plagioclase are present. There is a fair number of rather small grains of magnetite and a little apatite.

Thus these rocks are syenites belonging to the variety rather rich in both quartz and plagioclase felspar, and so somewhat intermediate between typical quartz-syenites, and quartz-diorites.

(3) *Details of the Northern Syenite.*—Proceeding now to New-Cliff Plantation, near Garendon Lodge, where two quarries in the northernmost patch, marked "Greenstone" on the Survey Map, afford the best opportunity for examining the rock, we find that it chiefly consists of a dull felspathic mineral, of a pale green colour, passing into pale red, and a dark green hornblende. Though at first sight the rock seems very different from that of the southern area, closer examination shows considerable similarity, this being less coarsely crystalline and rather more altered. It passes occasionally into a still more compact rock of a dull green colour. The rock is boldly jointed, with faces weathering of a reddish colour; it is overlain in places by nearly horizontal Keuper.

We noticed the Longcliff exposure in Part I. (p.788). In general character it resembles that of Garendon, though perhaps it is a shade more finely crystalline; and on approaching the sedimentary rock it passes into a very finely crystalline rock of a dull green colour, weathering brownish. A variety at the south end exhibits a slightly foliated structure. The same may be said of the mass of Buck Hill, where the rock also puts on a "greenstone" aspect near the junction with the sedimentary rock. About halfway between the Longcliff and Hammercliff exposures is the Bawdon-Castle patch, which is probably not quite so extensive as it appears in the Survey Map; though, as the ground is in many places strewn with large boulders, partly buried in the soil, it is often difficult to say whether the rock is or is not *in situ*. The best exposures are in two copses on the higher ground. In the northern of these the rock, which is fairly well shown in a shallow pit at one end, is, on the whole, rather of the Garendon type, but a little coarser and more decidedly mottled with light red, one specimen which we collected coming very close to a fragment from Hammercliff. In the two fields between this and the next wood are numerous scattered boulders, both of syenite and sedimentary rock. In the latter wood is a most interesting exposure. The syenite forms a small steep boss. The heart of this is a rock which, though a little more finely crystalline than the normal Garendon rock, might be matched by specimens from that quarry. In the course of a few yards it passes at its N.N.W. extremity into a very finely crystalline "greenstone," in which faint light red specks can barely be distinguished on a broken surface, though they are a little more evident on one that is polished. About two feet off the last outcrop of greenstone (or a yard or so more, if that be not *in situ*) is a large mass of the pecular volcanic grit already described (p. 202), and beyond it a still coarser grit with a band of fine slate. That the former of these is *in situ* we have no doubt, so that a junction between sedimentary and igneous rocks is all but exposed here.

If it had been necessary to separate the northern and southern syenites, we should ourselves, judging from the general character of the Bawdon rock, have classed it with the northern group. It seems, however (and this view is confirmed by microscopic examination), that there is no reason for any such separation, the rock of Hammercliff and the coarser variety at Bawdon Castle completely linking the two extreme normal types of Groby and Garendon. The mode of occurrence, the greater change in crystalline structure near the exterior of a mass, and the possibly slightly more basic character of the northern rocks, indicate probably that they were rather less deep-seated intrusions.

Microscopic Structure of the Northern Syenite.—Specimens of this rock have been examined from the Garendon Quarry, Longcliff, and Bawdon Castle, the first being the most typical. The rock is more affected by decomposition than those which we have been describing, but is one of the same general character. There appears, however, to have been a little less quartz. Viridite, chlorite, and epidote to a great extent replace the hornblende; and the usual secondary microliths and kaolin, with more or less of these other minerals, the felspar. So far as can be ascertained, both kinds of felspar have been present. The graphic structure is shown, but is generally more minute than in the other syenites and of the arborescent form. Apatite is not uncommon. The peculiar grey-brown, slightly transparent, aspect of the decomposed grains of iron oxide, and the black lines indicating cleavage-planes, show that much of it is here present in the form of ilmenite.

The Longcliff specimen is taken from the south end of the ridge, from near a junction; its composition is similar to the above, but it is still more decomposed, and has a rather foliated structure (probably due to pressure), which can be seen in the hand-specimen. It is rather rich in apatite.

Two specimens have been examined from the boss described in the second wood at Bawdon Castle. One of these, a finely granular dull-green rock, is from quite the exterior of the boss; the other is like the Garendon rock, but much more finely crystallized. But for this the latter variety does not seem to differ very materially from that rock, except that the ilmenite seems to be partly replaced by the clear green mineral already noticed (p. 205). The exterior rock is, on the whole, somewhat better preserved; it has evidently consisted of rather long crystals of plagioclase felspar, hornblende, and magnetite or ilmenite. The hornblende has been affected in the usual way, and the felspar also, except that it is rather more pellucid than in the last. There has been some orthoclase, but most of the crystals, judging by their form and remains of twinning, have been plagioclase. This change, however, towards the exterior of a mass is not unusual; still if any one confined his examination to the slides, he might have a little difficulty in believing them to be from the same boss of rock. A few traces of the graphic structure may be observed. The iron peroxide here has more the appearance in decomposition of magnetite, but it is not very characteristic.

Hence this group of rocks may also be classed with the Syenites, though approaching yet a little nearer than the others to the Diorites; and, as already stated, we consider them, both physically and lithologically, as forming a single series.

(4) *Hornblendic Granite of the Quorndon District.*—The rock occurs as an insulated mass near the eastern edge of the Keuper, dominating the left bank of the Soar valley. The principal portion of it forms the great tree-clad hill called Buddon Wood, from which a large spur runs out to the east, terminating at the village of Mount Sorrel, in the noted hill of the same name. There is an outlying patch crossed by the Loughborough Road on the N.E., and two in a line to the S.W., that of Kinchley Hill and the small knoll in Brazil Wood. All these are probably connected beneath the Trias in the same way as the southern syenites, though the last-named patch is more isolated than the rest. About 100 yards to the S.S.W. of this the unique gneiss of Brazil Wood (p. 783) forms a knoll. This is the only indication of the limit of the *massif*, what is now visible being simply the tops of granite hills rising above the encircling Trias as from a sea*. Besides the extensive quarries of Mount Sorrel, smaller quarries exist near Quorndon and elsewhere, and the rock is generally easily examined, except in part of Buddon Wood, where it is overgrown by vegetation. The normal rock is a not very coarse, pinkish granite, S. G. 2·65 (Ansted), consisting of quartz, felspar, black mica, and dull green hornblende, with occasional pyrite and epidote. In the Mount-Sorrel pit there is also a greyer variety in which the pink tinge is almost absent from the felspar. As in the syenite, so here, there appears to be no law regulating the occurrence of these varieties. Infiltration or contemporaneous veins of a pink felsitic rock are common in places; and there are some dykes to be presently described.

The granite is occasionally slightly porphyritic in structure, the

* The Mount-Sorrel pits show excellent sections of the Keuper, containing granite boulders at the base, resting on a very irregular surface of granite. This, near the entrance of the pit, is known to descend for many yards almost vertically. Considerable difficulty was found in completing the foundations of a crane, one side of which rested in the live rock. A well at the engine-house about 100 yards from this has been sunk in the Keuper to 100 feet without reaching the granite. On the edge of the upper part of the hill is boulder-clay resting apparently in a valley scooped out of the Keuper. The rock above seemed to bear (in 1873) faint indications of glacial action on its generally roughened prominences. Mr. W. J. Harrison, in his useful book 'Geology of Leicestershire,' gives a good account of the Forest drift and a photograph of the granite rock.

ground-mass becoming more finely crystalline. Sometimes it is much decomposed near the surface, and the hill is found to be traversed by two (or more) nearly vertical bands of rotten rock (one 15 to 25 feet wide) defined by joints running roughly north and south, called "mush" by the quarrymen. There are generally three or four systems of joints cutting the rock into rather irregular masses, the best marked being the one running as above. In the lower part of the pit these joints are so well defined as to give the rock quite a platy aspect, and are cut by another set, further apart, sloping at about 60° *. These, as we were shown, dipped rather to the west higher up the hill, and on the other side of the crest were reported to dip steeply in the opposite direction. The rock is often slickensided; and the joints coated with mineral substances, resembling sometimes hæmatite, sometimes chlorite. Pyrite is seen in the rock and veins, and nests of quartz and epidote, also sulphate of baryta, bitumen, and a little carbonate of copper. Mr. Harrison states that molybdenite has been found.

Microscopic Structure of Mount-Sorrel Granite.—The red and grey varieties have both been examined. The former consists of well-crystallized quartz, felspar, biotite, hornblende, and magnetite, with a little apatite. The quartz and felspar are occasionally intercrystallized, so as to offer a slight approach to the graphic structure already described. The quartz contains minute cavities and microliths, but is otherwise clear, and shows brilliant colours with crossing Nicols. Some of the felspar is a good deal decomposed, and is replaced by zeolite mixed with brown dust. Most of it appears to be orthoclase, but, as in the syenite, there is a fair quantity of plagioclase, probably oligoclase, which seems to have escaped better. Some crystals exhibit zonal banding. The hornblende is not very characteristic, is a good deal decomposed, and partly replaced by epidote. The biotite has predominated, part of it being very well preserved. Some crystals are more or less replaced by a clear greenish mineral, strongly dichroic (in a few instances showing aggregate polarization), seemingly of the same crystalline system; its action, however, as an analyzer is comparatively slight, the pseudomorph only very slightly darkening its colour, while a biotite crystal so used when lying in the proper position is almost black. The grey variety is, under the microscope, almost undistinguishable from the last, the difference in colour being apparently due to a different tinge in the earthy part of the decomposed felspar. One of the dark, apparently included, fragments has been examined. It consists of crystalline quartz in tolerably large grains, in which are irregularly scattered longish prismatic crystals of decomposed felspar and of fibrous hornblende, numerous grains of magnetite, and very many belonites; these last are colourless, and generally less than ·01 inch long. So

* The foreman told us that the rock had a kind of "cleavage" parallel to these joints, so that a workman who knew the pit could make in an hour or two as many paving-sets as a stranger could in a day. Also that this "cleavage" on approaching the joint-planes curved a little towards them, clearly indicating some approach to a fissile structure.

far as can be ascertained they belong to the monoclinic or triclinic system, and perhaps are only hornblende. The line of division between the above dark spots and the granite is tolerably sharp, and it seems probable that they are included fragments of some other rock almost melted down, rather than segregation nodes in the granite.

(5) *The later Intrusive Rocks.*—The principal dyke in the Old Pit at Groby is on the western side. It runs in a general N.W. and S.E. direction, dipping at a high angle to the east. The thickness is variable, often about two yards, but we were informed that at one place this had been considerably exceeded. At our last visit in 1877 it appeared to be thinning away at the north-western end of the pit, and exhibited very interesting junctions with the syenite, which it has broken up, injecting itself into fissures and enveloping fragments. We obtained a specimen with a strip of syenite about two inches wide, included between two pieces of greenstone. In the thicker part this appears as a finely crystalline greyish-green rock of pretty uniform colour and texture, except that here and there are a few light-coloured felspathic spots. In the thinner parts, and near the junction, it becomes quite compact, a little paler and greener in colour, showing many minute dark granulations and a slightly streaky structure parallel to its junction surface. A few feet to the right of this is a another narrow, somewhat irregular dyke, rather rotten and broken up, of a rock resembling the finer variety of the last, very probably a branch from it; but, as it was said to thin out on approaching the floor of the pit, this has not yet been proved. We were informed that another dyke had once existed which had crossed the floor of the pit, making an angle of about 60° with the first named, but all trace of this has now been quarried away.

Under the microscope the coarser variety of the first dyke exhibits an irregular network of longish felspar crystals, mostly plagioclase, but very much decomposed, or more or less replaced by the usual pseudomorphs, the interstices being occupied by viridite, hornblende, and possibly a little chlorite. Opaque grains, apparently of magnetite, are thickly scattered about, with a few larger hornblende crystals, generally much decomposed; there is also a little quartz, calcite, and possibly dolomite. The finer variety, close to the junction with the syenite, shows a number of small crystals, pseudomorphs after plagioclase felspar, lying with their longer axes roughly parallel to the junction surface, in a ground-mass tinged with viridite and thickly crowded with black or nearly opaque brown granules. With crossed prisms the ground-mass exhibits an indistinct microcrystalline structure with traces of a glassy base. These specimens probably represent only different conditions of the same rock. Though now hornblendic, I have a strong suspicion that they were once augitic and true basalt. The percentage of silica in the more compact variety is, according to one observer 51·4, according to another 52·4 (Prof. Liveing), which is low for a true diorite, but not too high for a basalt (see p. 223).

Sheet-Hedges Dyke.—This dyke is a compact, dull green rock, of a slightly mottled aspect, and rather irregular fracture, weathering brown. It appeared to be about two feet thick; the junction was not very well exposed when we visited it. Under the microscope the ground-mass is a clear glass, thickly crowded with minute pale brown and green microliths, and traversed by a sort of irregular network of viridite, much of it the dichroic bluish variety, so that it is divided up into ill-defined rounded patches. Grains of magnetite (?), larger patches of viridite, and a good many long felspar crystals are scattered about. With crossed Nicols these rounded patches become more conspicuous, recalling a structure not infrequent in some lavas; the whole rock, however, is now a mass of pseudomorphs, all the felspathic element being apparently converted into secondary microliths; a very little quartz, probably of secondary formation, and a little dolomite (?) are also present. The rock may have been an andesite.

Bradgate-Park Dyke.—This dyke is well seen in the bed of the stream about one hundred yards below the last fish-pond; it is in general rather less than two feet wide, with distinct, irregular, and closely welded junctions, sharply and finely jointed, tolerably subconchoidal fracture, dull grey green-colour with lighter specks, and occasional distinct crystals of pinkish felspar. It is a rather heavy rock, weathering brown.

Under the microscope it appears to have a glassy base, thickly crowded with microliths of felspar or its pseudomorph; in this lie many larger crystals of felspar, apparently of both kinds (partly pseudomorphosed), the usual dusky grains, patches of viridite, probably replacing hornblende, and some calcite with a little quartz. The rock is probably an altered hornblende andesite.

Mount-Sorrel Dykes.—West of the principal quarry, a little below the summit of the hill, a dyke of compact pinkish-red felstone can be traced for some eighty yards. It strikes about N.E., dips at an angle of about 60° towards the eastern side, and is generally about six to eight inches thick; in two or three places it splits and includes small slabs of granite, in others thrusts in a small tongue. At the junction it sometimes flakes away from the granite, sometimes adheres firmly.

The base of the felstone dyke appears under the microscope to be a true glass, but very thickly crowded with granular felspar microliths, together with grains of iron oxide and a few needles of hornblende, all very minute. Somewhat larger crystals of felspar, orthoclase, with some plagioclase, are scattered about, their longer axes roughly parallel to the junction surface, and a little quartz; there are a few imperfect spherulites. The junction with the granite is clear and sharp, and one or two little fragments of it are included. This rock is not more ancient in aspect than some of the specimens of Hungarian trachytes, with which it might almost be classed *.

On the floor of the pit were picked up fragments of a thin vein of

* Mr. Houghton has determined for us the percentage of silica; it is 77·7, which proves the rock to be a true rhyolite.

a pink felsitic rock much resembling that described above. It has, however, a more distinctly crystalline ground-mass, a good deal of it showing an approach to the graphic structure. There are small quartz grains, but scarcely any distinct felspar crystals; it may be a branch of the above-described dyke, but there is no evidence to show.

In several places, and especially in a knoll south of Buddon Wood, numerous thin veins of a pink felsitic rock occur in the granite. These somewhat resemble intrusive veins, but are almost too string-like and ramified to have been injected when the mass was perfectly solidified. Further there never appears to be any tendency to separate along the junction-surface, and this, under the microscope, is not so clearly defined as in the other specimens. These veins are crystallized, though more finely than the granite, and do not seem to differ materially in mineral composition, except, perhaps, there is little hornblende or mica. Hence it seems most probable that they are contemporaneous veins, not intrusive in the ordinary sense.

In the upper part of the great pit is a large dyke of very different character, which has been traced for a considerable distance in process of quarrying, running from N.W. to S.E. (in June 1877 the latter end seemed to be curving more to the south); it is often about two yards thick, but varies; we saw no close junctions, but were told that these were formerly found. At present a fissure filled with breccia and rubbish is immediately above it on the north side. In general appearance it is very like the Groby dyke, but slightly more crystalline and better preserved; small bright crystals, apparently plagioclase, can be seen with a lens. On the floor of the pit we picked up a specimen showing a good junction between the granite and a rock resembling the finer variety of Groby, which also exhibited the streaky flow-like structure; probably this came from some offshoot of the main dyke, but we could get no certain information.

Slides have been examined of both the above varieties of greenstone. The coarser, in general structure, resembles that of Groby, but is in rather better preservation. The felspar is clearly plagioclase; the spaces between it are filled with viridite; there are a good many scattered grains of ilmenite &c., and some larger crystals of a partly decomposed pyroxenic mineral, of which enough remains to show almost to a certainty that it is an augite. The rock, then, is an altered dolerite*. The finer variety shows the remains of a glassy

* The Rev. J. H. Timins (Q. J. G. S. vol. xxiii. p. 364) gives the following analysis:—

Silica	54·39
Alumina	18·39
Oxide of iron	10·30
Oxide of copper	0·60
Lime	7·15
Magnesia	3·92
Loss on ignition	3·46
Alkalies and loss	1·79
	100·00

This agrees fairly well with analyses of one of the more felspathic dolerites.

base crowded with minute plagioclase crystals &c., doubtless the more glassy condition of the same rock.

Buddon-Wood Dyke.—This dyke crosses the granite pit in nearly an east and west direction (the greater part of the excavation being worked behind it), dipping about 70° to the south, and being about ten feet thick. Above it is often a fissure filled with granite breccia, but the junctions are sometimes close. It is a hard, tough, heavy rock of a dull reddish-grey or purplish colour, with dark green spots, and is minutely crystalline, showing occasional distinct small crystals of plagioclase felspar. In appearance it approaches nearer to some of the duller specimens of the compact syenite of Groby than the other above-mentioned dykes.

The microscope shows it to consist of altered plagioclase felspar, magnetite, viridite, and the remains of a pyroxenic mineral, not very characteristic, but rather more resembling augite than hornblende; some of the viridite looks like a pseudomorph after biotite. The rock is probably an altered felspathic basalt rather than a true diorite.

The Rev. J. H. Timins gives an analysis of this rock (Q. J. G. S. vol. xxiii. p. 364):—

Silica	51·23
Alumina	18·10
Oxide of iron	4·41
Oxide of copper	0·70
Lime	5·72
Magnesia	3·13
Loss on ignition	5·21
Alkalies and loss	11·50 (alkalies abundant).
	100·00

Mr. Harrison ('Geology of Leicestershire,' p. 11), who quotes this analysis, refers it to the felsite behind the Mount-Sorrel pit. The appearance of the rock itself negatives this supposition, and the silica percentage of the former places the matter beyond doubt. Mr. Timins did not collect the specimen himself, and so could give us no further information than what he had printed—"a red felspathic trap three quarters of a mile south of Quorndon." This, however, accurately describes the above locality, and not Mount-Sorrel pit; and he kindly sent us a fragment of a rock resembling the one he had analyzed (that having been lost), which was much more like this of which we speak. Hence we have no doubt of the identification. This dyke is the one mentioned by Professor Jukes.

Dyke in Brazil Wood.—The peculiar sharp jointing of this dyke, which is exposed in a little pit on the west side of the granite knoll, distinguishes it at once from that rock, but it is hard to trace owing to the character of the ground. It is a finely crystalline rock of a dull greenish colour, weathering brown, faintly speckled with a greyer tint, and showing a good many ill-defined spots of a somewhat decomposed reddish felspar.

Under the microscope it is seen to consist of a rather finely crystalline ground-mass of somewhat altered small plagioclase crystals interwoven with viridite, containing scattered magnetite, decomposed ilmenite (?), and several fairly large crystalline grains, which, on examination, are found to be made up of aggregated hornblende; this is feebly dichroic, and its general aspect suggests that it is a secondary product. Except in this respect the rock still much resembles some of the more compact less basic plagioclase basalts.

Knoll of Diorite, north of Brazil Wood.—This rock is in good preservation, and remarkably tough and refractory; it is distinctly crystalline, rather variable in texture, but generally coarse, dark in colour, weathering brown; macroscopically consisting of whitish plagioclase felspar, with glittering faces, and black, fairly lustrous hornblende. Under the microscope the latter mineral is seen to occur in irregular grains, plate-like in section, pierced and intersected by the plagioclase, with a little iron peroxide (?some of it ilmenite). The hornblende with transmitted light is both brown and green in colour, and much of it and of the felspar is still in good condition. Here and there, however, patches of the pale fibrous actinolitic variety occur, associated with a mineral rather like a fibrous variety of serpentine. These last are certainly secondary products, and much resemble a combination common in the altered Cornish gabbros. Most of the larger hornblende is strongly dichroic; some of the brown variety resembles biotite. One or two pieces, indeed, appear from their optical properties to be that mineral. There is a little calcite with characteristic cleavage. The plagioclase often shows brilliant colours and characteristic twinning, with occasional indications of a zonal structure. Microlithic enclosures are frequent. The microscopic examination can scarcely be said to confirm the relationship between these two rocks, which is not only suggested by their juxtaposition, but also favoured by the occurrence of diorite boulders in the wood between the two localities. It is remarkable that two rocks unique in the district, the above diorite and the curious gneiss* already described, occur within a very short distance

* The microsopic structure of the Brazil-Wood gneiss is described at p. 783. Since the publication of that, Mr. Houghton has kindly favoured us with the following analysis:—

Composition of the Rock dried at 100° C.

	per cent.
Water	4·23
SiO_2	54·01
Al_2O_3	21·87
Fe_2O_3	5·38
FeO	6·24
MnO	0·63
CaO	2·13
MgO	1·30
K_2O	3·66
Na_2O	1·00
Total	100·45

The sp. gr is 2·85.

of each other and of the granite. A little excavation in this wood might bring to light interesting results.

These are all the dykes with which we are acquainted in the district. Professor Jukes mentions a basaltic dyke in Simpson's pit towards the east end of Mount Sorrel, but for several years all trace of it has been lost. It will be observed that, except the last described and the Mount-Sorrel felsite, they appear to be rather closely related in character; and could they have been seen when fresh would probably have then been named either rather felspathic basalts, or andesites poor in silica.

Probable Outliers of the Charnwood-Forest Rocks (Narborough District).

As to the extension of the older rocks of the Forest beneath the Triassic lowlands, we have hitherto known next to nothing, except that syenite is said to have been struck in a boring at Baron Park, $6\frac{3}{4}$ miles west of Leicester, at a depth of 118 feet. Probably they lie at no very great depth under the Trias of the district to the south, for four or five masses of igneous rock, of a rather similar character, are found rising above the Keuper, in the vicinity of Narborough, sometimes rather boldly, as the syenite does in the Forest region. These occur at the following localities: Enderby, Narborough, Croft Hill, Stony Stanton, with Sapcote and Barrow Hill (see fig. 1). Enderby is about five miles due south from the Groby *massif*; the next three places lie roughly on a line running for about five miles S.S.W. of it, and the masses of Sapcote, Stony Stanton, and Barrow Hill, not more than one and a half mile apart, are on a line, which, if prolonged to the north, would about pass through Markfield. We have once or twice visited the quarries in these rocks, but have not studied the masses in the same detail as those in the Forest proper. Still, as we have examined, microscopically, specimens from each locality, we may be able to add something to what is known about them.

Commencing at Enderby, we found that the prominent knoll on which the village of that name stands consists of igneous rock, in which are sundry excavations; but the principal quarries are worked in a small, isolated exposure in the lower land south-east of the village, surrounded and almost overlain by Keuper Marl, resting as usual on an irregular surface, and with boulders at the base. The rock here is generally uniform in character, somewhat resembling the finer variety of the Groby syenite. It exhibits a compact ground-mass, with numerous small glittering felspar crystals, many of them plagioclase, and a few grains of quartz. Here and there are irregular dull green patches, sometimes half an inch or so in diameter, the smaller of which rather resemble decomposed hornblende; the larger, nodes in which much of this mineral is present. The rock, in colour, varies from a dull purplish or pinkish red to a greyer red (the latter being apparently due to incipient decomposition) mottled, as has been said, with dull green.

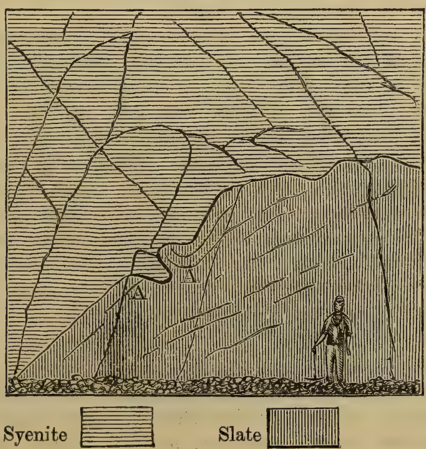
It has the aspect of a porphyritic felsite rather than a truly granitoid rock, though occasionally (especially when a little decomposed) it seems nearer to the latter in texture. Under the microscope, a slide from one of the best-preserved specimens shows the ground-mass to be microcrystalline, composed of quartz granules and brownish

Fig. 1.—*Sketch Map of Charnwood Forest, with the Narborough District.*

Horizontal shading, slaty rocks; cross shading, igneous rocks. The arrow-head points to the position of the Enderby slate.

decomposed felspar, in which are scattered larger crystals of felspar, microliths and irregular crystalline grains of hornblende, grains of magnetite, and perhaps of ilmenite, some of quartz (larger in size) and small hexagonal needles of apatite. With crossed Nicols the ground-mass rarely shows any brilliant colours, various shades of pale yellow, milky white, and dull purple prevailing. The larger felspar crystals, most of which are plagioclase, are also dull in colour, though generally in fair preservation. Some, however, are replaced by the minute bright-coloured microliths already noticed. The quartz is generally rather free from cavities, and such as exist are very small in size. The larger hornblende crystals, as has been said, are often aggregated: they are rather irregular in form, and appear to be affected by decomposition; possibly some are pseudomorphs after biotite. These last contain many irregular microliths and aggregated specks, some of magnetite (?), others of a semiopaque brownish granular mineral, which also occurs in other parts of the field. The larger ferruginous grains are also more abundant among the hornblende clusters. There is not much viridite in this slide, and no distinct epidote. The rock is generally nearer in structure to the felsites than to the normal syenites, and would fall into the intermediate class, syenite-porphyry, adopted by some petrologists. In the south-west corner of the pit is a most interesting section. Here we find a highly altered stratified rock. This is generally much stained and decomposed, so that its nature is sometimes hard to recognize; but careful examination shows it to be a dull green, distinctly banded, slate, very like some of those in the Forest. The syenite, as shown in the diagram (fig. 2), is clearly intrusive in it, and partly overlies

Fig. 2.—*Diagram of Junction of Syenite and Slate in Pit South of Enderby.*



A A. Indications of bedding visible here.

the slate, so that very probably the latter was not exposed to view until the pit was opened. There was last summer an excavation, about six yards wide, below the general level of the pit, showing the slate on both sides for a distance of about eleven yards. On the south side it rises rapidly to about fifteen feet above the floor, rather more at the end, and is overlain in the vertical wall of the quarry by perhaps eight yards of syenite. On the other side, and at the south-west end, it rises to much the same height, but the syenite has been quarried away. At this end of the excavation some still remains resting on the slate, and we were informed that the latter had been exposed in quarrying away the syenite for about twenty-five yards to the west-south-west, and might still be seen, when the water was low, in a part of the excavation not yet filled up by débris. The other excavation also generally contains much water, the presence of which probably accounts for the decomposed condition of the slate. The slate is much crushed and indurated near the junction, and is so much disturbed that we cannot reason upon the indications of its dip, which, so far as can be seen, is towards the north or north-east. There is hardly any appreciable change in the crystalline condition of the syenite as it approaches the slate, so that the whole mass must have been at a high temperature when the former rock broke through it. We think we may, without hesitation, refer the slate (which is rather like that of Billabarrow) to the Forest series, which is thus proved to extend five miles further south than has hitherto been known.

The syenite of the main mass beneath Enderby village, as shown at Mr. Rawson's quarries, on the north side of the hill, is a little more distinctly crystalline, and is almost undistinguishable from that of Croft Hill described below. Here, too, a little of the Keuper Marl yet remains, showing that these knolls were once almost, if not wholly, buried beneath that deposit.

The patch of igneous rock at Narborough is not marked on the Survey Map, doubtless because, at the time the survey was made, it was concealed by overlying Keuper, or surface soil. Within the last few years, however, a large and deep pit has been opened. This is situated in a small knoll just outside the village on the west and to the north of the Huncote Road. The rock in general appearance somewhat resembles that of Enderby, but the ground-mass is decidedly more compact. The fracture also approaches nearer to conchoidal. The felspar crystals are smaller; many of them are of a rather bright red colour; and the dull green patches are much smaller and less abundant. The microscopic structure corresponds, showing the ground-mass of the slide to be microcrystalline, consisting of grains of quartz and felspar; the larger crystals scattered therein are rather more altered than in the last rock; but, so far as we can ascertain, orthoclase seems to predominate. The green mineral is generally viridite, which has doubtless replaced small hornblende crystals; here and there, however, a little of the latter mineral remains unchanged, and there is a little dolomite (or a mineral resembling it). There are fewer grains of magnetite than in the last; a little epidote may occasionally be detected. This rock, then, may be classed with the quartz-felsites.

Rather more than a mile further west another mass of igneous rock emerges from the Trias, forming the conspicuous eminence of Croft Hill. There are large quarries near the villages of Huncote and Croft. In the former, the usual irregular surfaces, with syenite boulders in the base of the overlying Trias, are well exhibited. One set of master-joints, called, locally, "slithers," is very conspicuous in the pit; and another parallel and closer set, oblique to these, gives a kind of bedded appearance to the rock. This has a general resemblance to slightly weathered specimens from Enderby, but is rather more distinctly crystalline in texture. Under the microscope, this apparent difference is shown to have a real existence, the rock being distinctly crystalline-granular. Throughout the slide, though the rock is much decomposed, quartz (some of it probably of secondary formation), felspar, and a green hornblendic mineral are visible. A good deal of the last mineral, however, is not hornblende (though probably a pseudomorph after it or biotite), but the fibrous mineral already noticed. The felspar is both orthoclase and plagioclase, but the latter is quite as abundant as the former. Magnetite and the usual decomposition products are present*. There are occasional slight indications of a graphic structure. The rock, then, is intermediate in character between the syenites and diorites; but, on the whole, it will probably be best to rank it among the former, and with the quartziferous varieties.

The rock in the Croft quarries is macroscopically undistinguishable from the last. There are here interesting sections of Boulder Clay resting in an excavation in the Keuper, which overlies the syenite in the outer part of the pit. The rock is also exposed in the village of Croft, and there are some small quarries just outside that place, across the brook. It appears everywhere of the same general character.

The syenite at Stony Stanton also forms an eminence on which the village is built. We examined a large quarry at the entrance. The rock here exhibits very conspicuous master-joints at intervals of four or five yards, inclined at a considerable angle to the horizon, more uniform and regularly parallel than in any of the other pits. It is a little redder in colour than that of Croft Hill or Lower Enderby, and rather intermediate in texture. The microscopic structure does not differ much from the last, except that there is more hornblende, and a still nearer approach to the graphic structure. There is also a little more quartz. The felspar is generally altered, being replaced by the usual pseudomorphs, but both orthoclase and plagioclase are present. The rock, then, may be classed with the last described.

In the Sapcote *massif* several pits are opened: most of these are in the S.E. part, on each side of the Narborough and Hinckley road. The easternmost of these (north of the road) is at present of no great size; the rock exhibited two rather well-marked sets of master-joints, dipping respectively N.W. and S.S.E., but nothing

* We have observed many of the phenomena described by MM. Poussin and Renard in their admirable memoir 'Sur les roches plutoniennes de la Belgique,' &c. pp. 28–32.

else noteworthy. Just west of it, a windmill stands on a low knoll of the same rock, and some shallow pits have been opened. About 200 yards south of the road is a much larger pit. One set of joint-planes here rather dominates over the others, and the texture of the rock is perhaps slightly coarser than in the last-named pits. Epidote is common. Enclosures of a darker and more compact, and also of a coarser, rock are not rare, resembling, at first sight, included fragments (the latter are not unlike the syenite of Cliff Hill); but, on the whole, we are disposed to regard them as nodes. North of the road, a little further on, is a still larger excavation, the Sopewell quarry: the stone is much like the last, and very tough. Felspar, epidote, and hornblende, coarsely crystallized together, sometimes occur, apparently as nodes, but the specimen shown to us was not quite conclusive.

In this pit was the remarkable face of polished rock photographed by Mr. W. J. Harrison in his 'Geology of Leicestershire.' A portion of it remained at the time of our visit; the irregular surface forbids the idea of glacial action. Some sand is in contact with the rock, to which the polish may be due. This rearranged sandy deposit had a general resemblance to a mid-glacial or post-glacial drift; and we were informed that a well at the cottages near (called Granitethorpe) had been sunk in Boulder Clay; some of this was still lying about the mouth. As this clay is decidedly at a lower level than the sand, the latter is probably post-glacial. Two pits exist in the north of the *massif* on the right of the road leading to Stony Stanton from Sapcote; the larger exhibits well-defined jointing, and some thin, compact, contemporaneous veins, with occasional nodes rather resembling the rock of Garendon. A rock of similar appearance occurs in one part of the other pit. Just beyond this is a shallow valley dividing the *massif* from that of Stony Stanton.

The last exposure is at a place called Barrow Hill, about a mile and a quarter S.E. of the village of Earl's Shilton. Notwithstanding the name, the *massif* here is less conspicuous than usual, as it forms merely a slight flattened boss amid generally low ground, so that it may be convenient to notice that a windmill marks the spot from a distance. Here are several rather shallow pits, into two or three of which we entered. We were at once struck with a marked difference in the general aspect of the stone, which is of a dull grey colour, with a slight greenish tinge, faintly speckled with pale dull pink. The exposed portion of the rock shows a slight approach to a spheroidal structure, and its whole aspect reminded one of us, who is familiar with the Warwickshire diorites, more of them than any other rock in the Forest had done. One pit exhibits a redder variety, which presents a considerable resemblance to the Stanton Rock. This seems to overlie, though irregularly, the greyer rock; it is separated from it by so sharp a line of demarcation, that at first sight it resembles an intrusive junction. No other evidence of this could be found; and examination of a slice from the junction shows that the change is only a chemical one, due to the presence of red peroxide of iron, to which, as is readily seen under the microscope, the prevailing colour of the other rocks of this district is due. A slide of the normal rock consists of felspar, rather decomposed, but chiefly, so far as can be ascertained, plagioclase, a little quartz, mostly interstitial (an approach to graphic structure being sometimes shown), a fair amount of hornblende, some rather fibrous, some characteristic, and of magnetite, often in well-marked crystals. In the slide exhibiting both varieties there seems to be a slight difference in texture just along the line of junction; and near it in the red variety is a patch or two of calcite, with some rosette-shaped aggregates of chlorite. These are not common in the Forest rock, where the isotropic viridite is the more usual decomposition product. This rock, then, is rather a quartz diorite than a syenite.

We see, then, that these rocks, which are probably only the projecting summits of a much more extensive tract, are obviously long anterior to the Trias, and are doubtless part of the same physical system as the Forest.

Lithologically, also, they are closely related to the syenites of that district, though plagioclase felspar is a little more abundant, and the crystalline condition of the patches nearest to the Forest is rather different. The latter distinction, however, is not of much importance. All things considered, notwithstanding the dioritic character of the Barrow-Hill *massif*, we are of opinion that their chronological relations are with the Charnwood syenites rather than with the Warwickshire diorites (which are only eight miles from Sapcote), so that they may be safely assigned to a period anterior to the Carboniferous. Our recent discovery of the slate at Enderby, described above (p. 227), confirms us in this opinion, so that the whole length of the area occupied by or resting upon the Forest rocks, measured from north to south, is not less than seventeen miles.

Faults of the Forest Region.

It will have been seen from the first part of this paper that the beds of Charnwood Forest have been much dislocated. The exact course of the dislocations can hardly ever be traced, or their amount with any accuracy ascertained. The only exception is the great fault running along the anticlinal axis. This passes from Whitehorse Wood on the north by Ives-Head Lodge, down the valley between Ives Head and Shortcliff, and leaves Charley Knowl on the west. Its position with reference to Bawdon Castle is not known, but the syenite there may well have come up through it as a line of weakness. It appears to pass between Black Hill and Green Hill, skirts the east side of Benscliff Wood and the west corner of Blores Hill, crosses the corner of Bradgate Park about a quarter of a mile from the Holgate Lodge, and disappears under the Trias.

At the northern end the beds on the eastern side are below those on the western so far that the whole series of the Charley and Ives-Head rocks are invisible. The thickness of these beds cannot be less than 1500 feet. The Timberwood-Hill coarse ash-beds are also unknown on the eastern side. Considering their wide range to the south, and their power of resistance to denudation (for they almost always occur capping knolls), we should certainly expect to find traces about Moorley Hill if they reached the surface. The throw required to hide them would be about 2500 feet. If we correlate the High-Towers slate-breccia with the Longcliff ash-bed (a precarious identification), and on that basis calculate the throw, the result is about 3000 feet. This may be considered a maximum, for the Longcliff bed is below the position we should expect for that horizon, and the accumulations of agglomerate may render the beds about High Towers thicker than elsewhere. Thus on the whole the throw of the fault at the northern extremity seems to be certainly between 1500 and 3000 feet, and probably a little over 2500. The throw at the southern extremity has to be calculated by the positions of the great slate-breccias of Blores Hill and Holgate Hill. The uncertain position of the fault and the different directions of strike again preclude exact calculation, but it is evidently far smaller than that at the northern end. The best estimate we can form makes it 500 feet. The dislocation therefore must diminish to the south, and probably dies out not far beyond the limits of the district.

We estimated that at the northern end the western side of the Forest is raised 2500 feet above the eastern. Professor Hull estimates it as 2200 feet above the Coal-field. So near an equality raises a suspicion that the two faults may be due to the western region having been lifted in one mass; but, according to Mr. Coleman (quoted in Ansted, p. 23), the mountain limestone which at Gracedieu comes to the surface, has been found at Sheepshead, and therefore east of the anticlinal, at a depth of about 500 feet. This leaves 1700 or 2000 feet of faulting which must have occurred before the Carboniferous epoch. Thus the anticlinal fault, and probably also the present configuration of the country, must be to a great extent Precarboniferous.

The beds on the eastern side of the anticlinal seem on the whole wonderfully free from faulting. It might be expected that the syenite intrusions at Newcliff, Longcliff, and Buck Hill would have disturbed the strata. We have as yet obtained no evidence of this. In the country south of the Loughborough Lane, the positions of the beds correlated on horizon 1 (at Forest Gate, the Hanging Rocks, and the Brande) seem to show that no considerable dislocation can exist.

The case is quite different on the western side. We have shown in Part I. (p. 764) that a fault lies between Holgate Hill and Old John. This strikes west towards the syenite of the ruins. If the agglomerates of Old John and Ulverscroft Mill be, as we believe, the same beds, another probably lies north of Old John, abutting on the syenite in Newton Linford. We have suggested that these Ulverscroft-Mill beds are identical with those of Markfield (Altar Stone). As the lines of their strikes, if continued, meet between the two points, a curving of the strike would produce these positions without a fault. But the flexure would have to be rather sharp, and, as has been noticed, the beds at Sandhills Lodge are disturbed. A fault therefore probably runs from Markfield Tollgate by Sandhills Lodge, but whither further there is nothing to show. Its throw would be about 1500 feet. Nor is there any sufficient indication of the position of the disturbances due to the syenite of Hammercliff. The beds of Chitterman Hill lie about 1000 feet above the positions which would be occupied by those of Timberwood Hill, if they continued unaltered in direction; but that the direction would alter in the space of nearly three miles is little less than certain. It should be noticed that this dislocation is in the opposite direction to the preceding one.

The appearance of Bardon Hill, at right angles to all the other ridges, naturally suggests some faulting. Its structure, as described in Part I., shows that it is disconnected from all the rocks in the Markfield direction. There must be a fault down the valley between it and the Rice rocks. Very probably also, as Professor Hull suggests, another fault may pass along its north-western side somewhere to the north of Robin Butts. It is difficult to avoid supposing a third between it and the Green-Hill ridge, since the strikes are so different in the two localities, and since the great boundary fault which heads straight in this direction can scarcely have died out abruptly. Thus Bardon seems insulated by faults. The description of the last-named dislocation, which runs south-east through Whitwick, throwing down the Coal-measures against the Forest rocks, will be found in the Survey Memoir. Professor Hull there calculates, as we mentioned above, that the downthrow at Whitwick is about 2200 feet.

It was stated in Part I. (p. 775) that we had not been able to explain satisfactorily the relations of the Peldar-Tor rocks to those immediately S.E. of them. It seems almost certain that a fault forms the S.E. boundary of Peldar Tor, separating its beds from those of Tin Meadow and the Forest-Rock-Inn quarry. This hypothesis, however, still leaves some difficulties.

The S. dip a quarter of a mile E. of the monastery, and that to the S.E. on Kite Hill outside the garden, show the existence of disturbances which we cannot at present trace out. The rocks of Gun Hill appear to rise from below those of Kite Hill; but a re-examination of the beds shows that both the matrix and the included fragments resemble those of the Cadman series. We showed in Part I. that they were bounded by faults. This correlation would give them a downthrow of about 1200 feet.

A group of rocks whose position is probably due to faults is that E. of the grounds of Gracedieu Hall, at Warren Hill. They seem to come up from under the Cadman beds, and to overlie those of High Sharpley; but do not resemble those on Ratchet Hill, where the passage from one series to the other can be seen. The dips, though very obscure, can be made out at several points; they are always W.S.W. and gentle, except at one place, where there is a sharp roll or flexure, and the general succession of beds is clear. In descending order it is:—(i.) indurated slate, some extremely flinty; (ii.) coarse gritty slate of an ordinary type; (iii.) pale obscurely banded slates of ashy character, with a coarse grit-bed several feet thick; (iv.) a breccia containing fragments, about eight inches long, of a peculiar purple slate, and overlying a slate-bed of a greenish-purple tinge. Now there is a very similar succession of beds at the Forest-Rock Inn near High Towers, where we find indurated slates with one bed extremely flinty, a grit-bed in the spinney followed by rather ashy slates, and on the crest of the hill the great slate-breccia. The flinty slates from these two localities resemble each other and are very different from most others in the forest, which are usually of a paler green. The grits also differ from others and have some characters in common; for both contain felspar crystals as well as quartz, and some of the felspar is tinged pink. The fragments in the breccias are dissimilar in nature, but a bed below the High-Towers great breccia does contain some purple slate fragments. The Bardon-Hill section fails us just where these beds might be expected to come. Thus the evidence, we think, renders the equivalence of the Warren-Hill and Forest-Rock-Inn groups of beds probable, but does not convincingly prove it. If correct, since the space between Warren-Hill and the Cadman rocks to the W. is too short to contain the whole of the Peldar-Tor beds, and since an outcrop of the Sharpley rock, their equivalent, occurs a quarter of a mile to the E., Warren Hill must be enclosed by faults.

The flinty slate of the quarry N. of Whitwick, resembles that near Forest-Rock Inn. The possibility that they may be the same bed has often occurred to us, but such evidence as we can obtain does not confirm the idea. If they were the same the former would be much faulted, and it does show signs of disturbance. The Whitwick Breccia also seems, from its southerly dip, to be cut off from the general mass of the Forest rocks by a fault. This must run along the depression between the quarry ridge and High Cadman, and across the W. part of Broad Hill. It is very likely connected at each end with the Boundary Fault. Our uncertainty as to the correlation of these rocks prevents any estimate of their displacement.

The beds of the Charley and Blackbrook series appear less disturbed than those above them. To this series an outcrop (not mentioned in Part I.), N. of Gracedieu Hill across the dry canal bed, seems to belong. The eastern end is slate much jointed and stained; the western is a mottled ash, resembling a bed of the outcrop near Charley Wood. It is also on the direction of a line through the uppermost outcrops of these beds, a line not differing much from their strikes. Thus there is evidence of little dislocation along a line more than three miles long. This agrees with the absence of faults E. of the anticlinal, and points to the centre of disturbance having lain more to the west. This was the site of the principal volcanic activity during the deposition of the Charnwood rocks, and in this neighbourhood, in Postcarboniferous times, sheets of basalt were erupted over the Coal-measures.

Age of the Clastic Charnwood Rocks.

One of the writers has more than once called attention to the close resemblance which some of the Charnwood rocks present macroscopically to those of the Borrowdale series in the Lake district. This similarity becomes even more striking when both are studied microscopically. He has had the opportunity of examining some of Mr. Clifton Ward's collection of slides used in his important paper (Q. J. G. S. vol. xxxi. p. 388), and has also had a few prepared for comparison from specimens in his own collection. Two of these, altered ashes from the flank of Dod's Pike and the west side of Three-shire Stone, might readily be supposed to have come from such a district in Charnwood as the vicinity of the Monastery. The fragmentary felspar crystals and lapilli can be distinguished, and there are the same peculiarities of the matrix; quartz, however, in these happens to be wanting *, though it is present in other varieties. The Charnwood rocks have also a considerable similarity to the "porphyroids" of the Ardennes described by MM. Poussin and Renard †. There the same minerals are stated to occur—quartz with endomorphs, felspar of all kinds, fibrous hornblende, epidote, both ordinary viridite and the associated serpentinous mineral, and decomposed ilmenite. Many of their descriptions might be taken word for word, and the plates might be copied, to represent some of the structures of the Charnwood rocks. They have the same difficulty about the included crystals of quartz and felspar, and are of opinion that while many are certainly clastic, some may be formed in place. These Belgian rocks are considered to be of Lower Silurian age.

In the Survey Memoir and Map, as by most authors, the Charnwood rocks are called Cambrian, the term being used in the restricted sense in which it was employed by Murchison. The only evidence in favour of this correlation is that the Charnwood rocks are certainly old and unfossiliferous, and that they have an unusual strike, which, however, is not characteristically Cambrian. The authority of Professors Sedgwick and Jukes is often quoted in favour of their Cambrian age; but, as one of us has more than once remarked, this proves nothing more than that these authors thought them older than the May-Hill beds, seeing that they employed the term Cambrian in a sense so much wider than was afterwards given to it by the Survey. In the absence of palæontological evidence some weight may be rightly given to lithological; for lithology is a record of physical phenomena,

* Mr. Ward's analyses show that the ashes contain about 68 or 69 per cent. silica. I should expect the Charnwood would be the same. The lavas seem to be poorer in $Si\,O_2$, about 60 per cent. The Charnwood fragments, so far as examined, are decidedly rich in silica.—T. G. B.

† 'Mémoire sur les roches plutoniennes,' &c.

and there may sometimes be contemporaneity in these as in biological phenomena. Now neither at St. David's, the Longmynds, Llanberis, nor Harlech is there evidence of volcanic action in the (Survey) Cambrian. Volcanoes were active in the Lake district (as described by Mr. Clifton Ward) during the Lower Bala period of Sedgwick (Upper Llandeilo of Survey) when the Borrowdale series was deposited, and some of these rocks are most difficult (as has been already said) to distinguish from those of Charnwood. Further, the strike of the Borrowdale series, when last seen near Ingleborough, north of the Craven fault, is different from the ordinary strike of the Lake country, and roughly parallel to that of Charnwood. The rocks also of Cader Idris, and the neighbouring hills, which belong to this or some part of the Arenig epoch, present great lithological similarity, while there is but little to the Cambrian rocks of Llanberis, of the Harlech axis, or of the Longmynds. Hence it would seem far more probable that the Charnwood rocks belong to the same age as the Borrowdale series of the Lake district than to that of these Cambrians.

It must, however, be admitted that within the present year (1877) the argument for a Lower Silurian age has been weakened, without, however, materially strengthening that for a Cambrian, by the discovery (by Mr. Hicks) of agglomerates in the Precambrian rocks of Wales. Further the valuable and interesting observations of Mr. S. Allport* on the Wrekin introduce an additional complication. He has shown that ridge to consist to a very large extent of agglomerates with rhyolitic lavas (probably interstratified). One of us has had the opportunity of examining these remarkable rocks under his guidance. They have a strike roughly W.N.W. or a little W. of that, and there is great unconformity between them and the quartzites which flank the ridge. If, then, the latter rocks, in accordance with the views of Mr. Callaway, are at least of the age of the Hollybush Sandstones, *i. e.* not more recent than the Lingula-flags, it is very probable that the central ridge of the Wrekin, like the Malverns, is Precambrian (though much less highly altered). Lithologically, however, many of our Charnwood rocks seem more closely related to the volcanic products of the Lake district than to these devitrified rhyolites and pitchstones. At Lilleshall, however, to the N.E., is a small ridge, apparently belonging to the same series as the Wrekin, but probably rather higher up in it, in which some beds more nearly resemble the Charnwood rocks; and, finally, the analyses which we have obtained during the last few weeks of some of the fragments in the older parts of the Charnwood series show them to be richer in silica than, from their appearance, we had anticipated, for they even exceed in this the Wrekin pitchstones†. Hence, should the Precambrian age of their nearer neighbours be established, we must admit now that there would be much more real ground for refer-

* Quart. Journ. Geol. Soc. vol. xxxiii. p. 449.

† It is worth noting that the rhyolitic fragments occur in the lower part also of the Charnwood series.

ring the Charnwood series, also, to the same remote period than there has hitherto been, the arguments previously advanced in favour of this (except as regards their strike*) being wholly untenable. At present the case must be regarded as *sub judice*. If the verdict can ever be given, and it is for Precambrian, then the Charnwood rocks will probably correspond with the Pebidian series of Mr. Hicks.

Age of the Igneous Rocks.

If the age of the stratified rocks is uncertain, much more is that of the igneous rocks intruded into them. Let us, however, assume that the former are on the horizon of the Borrowdale series, and see if we can then attempt an approximation.

The Southern Syenites, as we have stated, are probably intruded among rocks rather high up in the group. The Groby rock (and we may say this of all in that district), according to Mr. Sorby, solidified at a great depth, certainly not less than several thousand feet. No Upper Silurian has been discovered nearer to Charnwood than the northern part of the South-Staffordshire coal-field†; and, so far as we can make any assumption with regard to the rocks of this period, we should infer that the series would hardly be so thick as it is in the Lake district. Hence we cannot suppose the syenite to have been intruded before the end of the Upper Silurian period. Now, having regard to the general configuration of the Forest, it is in the highest degree probable that much denudation had taken place before Lower Carboniferous rocks were deposited. The granites of the Lake district are intrusive in the Skiddaw Slate, Borrowdale series, and Coniston Flags (at Shap), and solidified at great depths‡. There can be no doubt that at any rate the Shap Granite must have been intruded about the time when deposition ceased and denudation and upheaval commenced—that is, about the commencement of the Old Red Sandstone period. Analogy, then, leads us to assign the same period for the Charnwood syenites. The correspondence of the strike in this district with that of the Borrowdale series, near Ingleton, suggests that the two lie on an area acted on by the same forces. We can hardly assign a later date to the hornblendic granite of Mount Sorrel; but, beyond the fact that it is almost certainly an intrusion in the gneiss§, of the age of which we are ignorant, nothing can be said. We may, however,

* Attention was called to this as suggesting a Precambrian age by Dr. Holl and others. See Woodward, 'Geology of England and Wales,' p. 24.

† Pierced in coal-sinkings near Cannock, and probably underlying all the coal-field to the north.

‡ According to Mr. Ward (Q. J. G. S. vol. xxxi. p. 589) the Shap Granite was consolidated at a maximum depth of 14,000 feet.

§ The extremely altered condition of this (which seems more than can be satisfactorily explained in this district by the proximity of the granite) suggests that it may possibly be a solitary fragment of a group earlier than that of the Forest rocks. There is some reason to think that the Malvern ridge exhibits Precambrian rocks of two ages.

venture to assert that a great mass of rock must have been removed from above it, and that, probably, in Precarboniferous times. The difference between this and the Groby rock is not sufficient to forbid us to assign them to the same igneous series.

With regard to the dykes, we may be almost certain that they are earlier than the Keuper, and were not intruded into deep-seated rocks. We should not therefore (though we have admitted them into this paper) regard them as Precarboniferous. Now at the Whitwick Colliery there is, between the Coal-measures and the Trias, a sheet of dolerite*, which has also been struck at Snibston, and the same rock has recently been pierced at Ellis-Town Colliery, one mile north of Bagworth station, the former two miles from the Whitwick pit, the latter about three. Further, there are frequent dykes of diorite in the Warwickshire coal-field, intrusive in Millstone Grit and Lower Coal-measures.

These greenstones of the Forest may, then, be of the same age as the Whitwick rock, and belong to that widespread igneous action which occurred in the lengthy period, not without its analogies to the Old Red Sandstone, which intervened between the end of the Coal-measures and the beginning of the Keuper†.

EXPLANATION OF PLATE X.

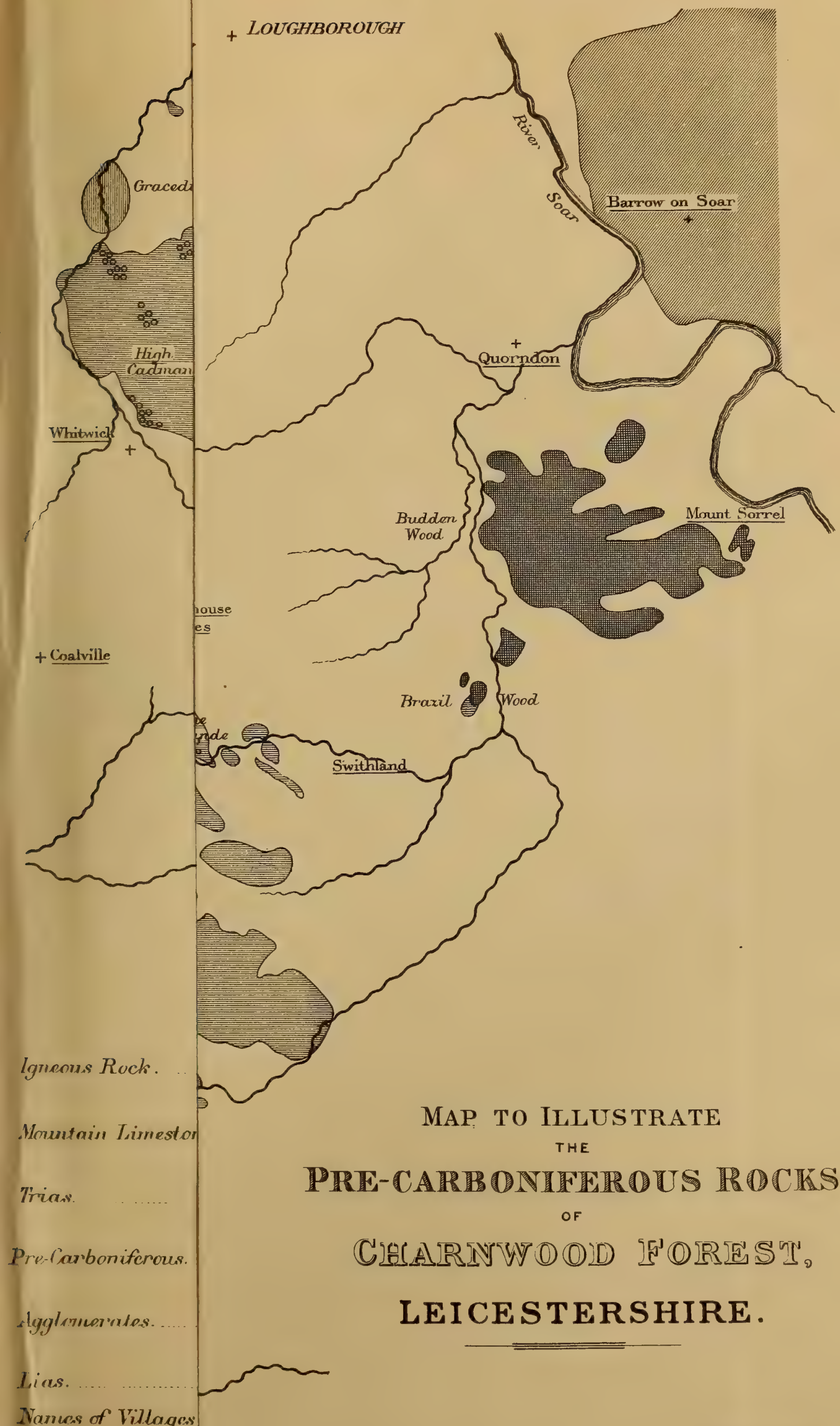
Map to illustrate the Precarboniferous Rocks of Charnwood Forest, Leicestershire.

Discussion

Prof. Ramsay said that this paper was one of great interest. In the days when the district under consideration was mapped by the Geological Survey the microscope had not been brought into use in geological work, and we are much obliged by the corrections it has effected in the broad nomenclature given to us by Sir Henry de la Beche. Of the masses down south, our greenstones were all dark-coloured rocks, in which felspar, and especially hornblende, predominated; where felspar and silica predominated they were regarded as syenites. With regard to the rocks of Charnwood Forest, after much thought, there being no evidence from fossils, the officers of the Geological Survey had come to the conclusion that they were probably of Cambrian age. The occurrence of Precambrian rocks in North Wales was spoken of in the paper as an established fact. He regretted that Prof. Bonney should be of this opinion; for all the evidence was entirely opposed to such an opinion. He maintained stoutly that there is an unconformity between the Lower Silurian and Cambrian. Last summer he went to Ireland, and saw it there

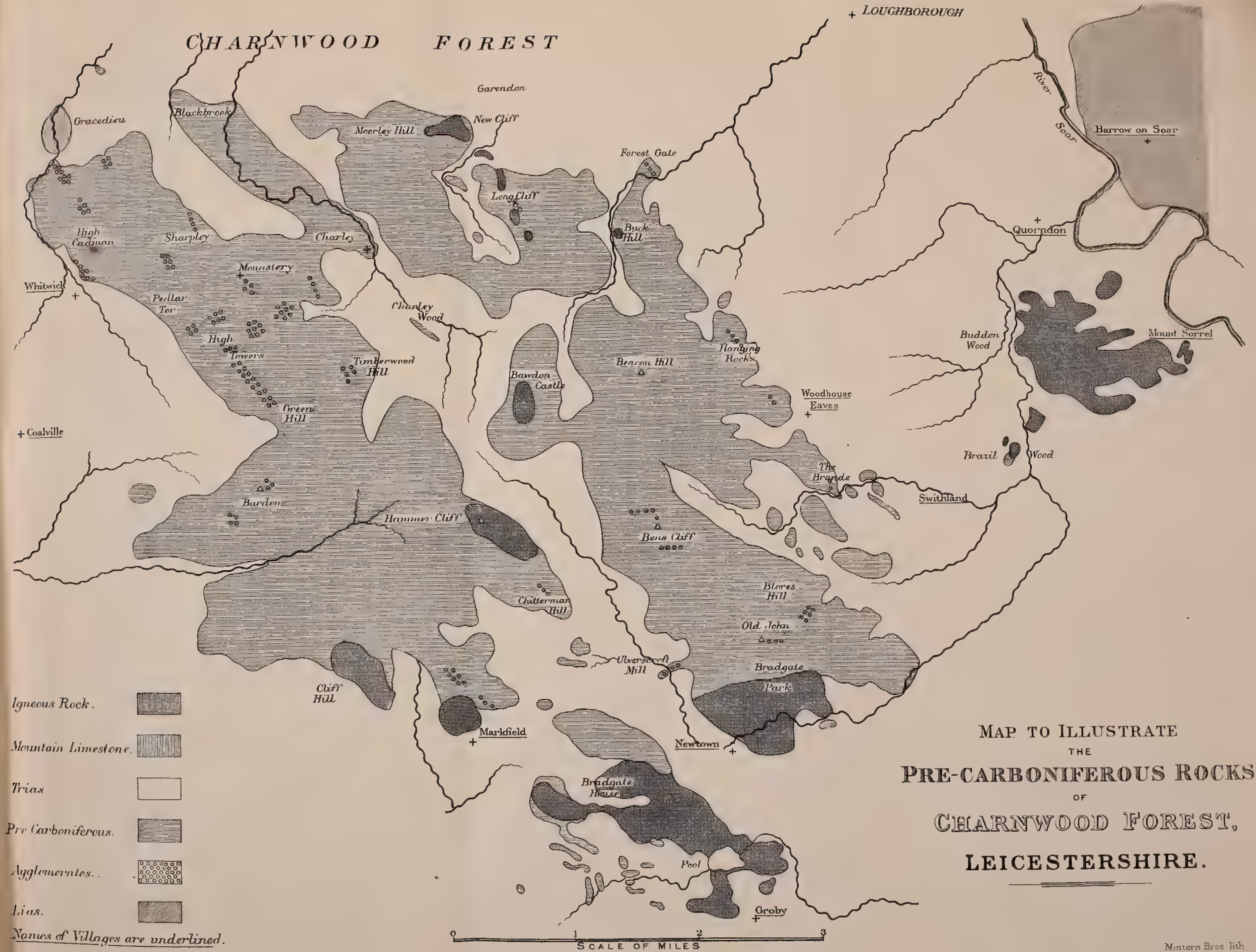
* See Allport, Q. J. G. S. vol. xxx. p. 550.

† The toadstones (basalts) of Derbyshire, however, show that submarine volcanoes existed to the north of the Forest at a rather earlier period.



MAP TO ILLUSTRATE THE PRE-CARBONIFEROUS ROCKS OF CHARNWOOD FOREST, LEICESTERSHIRE.

Mintern Bros. lith.



MAP TO ILLUSTRATE THE PRE-CARBONIFEROUS ROCKS OF CHARNWOOD FOREST, LEICESTERSHIRE.

also; and he brought the Irish Director-General to Anglesey, where he saw it, and was convinced.

Mr. Hicks said that he would not now discuss the questions raised in his late paper, alluded to by Prof. Ramsay, but he would willingly take six men into the field, and undertake to prove to them the truth of his views. He eulogized the clear method of the paper just read. The determination of rocks by fossils was easy, but here the age had to be determined by microscopic evidence. He believed that the rocks were not Silurian, but Precambrian; their general aspect unmistakably told that.

Mr. Whitaker inquired as to the age of the slate beneath the syenite in the junction represented.

Prof. Seeley thought that great caution was necessary in accepting generalizations which, to him, seemed hardly to be justified by the facts; as, for instance, from the presence of 70 per cent. of silica to conclude that a rock was a devitrified rhyolite. We must remember that infiltration largely alters rocks, and that laboratory experiments may give fallacious results. In volcanic ashes the broken felspar crystals would become disintegrated, and form clay; and this would occur in ancient, and not in modern rocks. The broken felspar furnishes uncertain evidence of age. Metamorphic rocks have been much and repeatedly bent, and thus the crystals might be broken.

Prof. Bonney, in reply, said that the presence of Precambrian rocks in North Wales appeared to him proved by the examination of specimens, and the evidence of competent observers. His examination of the Wrekin rocks under Mr. Allport's guidance had influenced him much. He could not answer Mr. Whitaker's question further than by saying that the slate appeared to belong to the Forest series. He defended himself against Prof. Seeley's remarks, and maintained that an experienced observer could speak decidedly as to the volcanic origin of rocks with broken crystals of felspar.

19. *The* Moffat Series. By Charles Lapworth, Esq., F.G.S.

(Read Nov. 21st, 1877.)

[Plates XI.–XIII.]

Contents.

Introduction.

§ I. *General characters of the Lower Silurian Rocks of the south of Scotland.*

No single geographical region in Britain is more clearly defined physically than the broad tableland known as the Southern Highlands or Uplands of Scotland. Cut off abruptly from the north of England by the shallow inlet of the Solway and the mountain-wall of the Cheviots, and from the main mass of Scotland by the great central valley of Lanark and Midlothian, it stretches like a vast zone across the entire breadth of the island from sea to sea. Occasionally some of its higher points are sufficiently grouped together to be classed popularly under a common title, such as the Moorfoots, Lowthers, and Lammermuirs; but the region, as a whole, may best be described as a rolling sea of broad rounded hills and deep narrow valleys. The only level spots occur along the banks of its few really important rivers, where their lower valleys expand into the long fertile reaches of which the Merse, Nithsdale, and Annandale are the most familiar examples. The more elevated areas, which rarely exceed 2000 feet in height, show here and there strips of peat moss or heathery moor-land. Nowhere, however, do we meet with the crag, cliff, and rocky ground of the Northern Highlands, but hill and dale are clothed alike in a universal mantle of soft green turf. The district is consequently preeminently pastoral, agriculture being almost entirely restricted to the low-lying, open dales.

The rocky floor of the whole of the Southern Uplands is formed of strata of Silurian age. Buried once, either wholly or in part, beneath portions of the Old Red Sandstone, Carboniferous, and Permian, these ancient deposits have again been bared to the action of the elements, which have carved them into that chaos of mountain and valley they now present. The largest surviving fragments of these later formations are the Red and Yellow Sandstones of the valley of the Tweed, and the Carboniferous and Permian rocks of the basin of the Solway. The remainder are mere local patches, scattered along the lines of the chief river-valleys.

Making exception of the narrow belts of altered strata that surround the granitic bosses of Kircudbright and Dumfries, these South-Scottish Silurians are as little metamorphosed as the equivalent deposits of Wales and the West of England. It might therefore be expected that the task of unravelling the physical and zoological succession among them would be correspondingly simple and easy. Unfortunately, however, such is far from being the case. Everywhere possessed of an accountable similarity in their lithological characters, totally destitute of fossils except in a few isolated localities, and, above all, thrown into the most violent folds and contortions, these ancient strata have been shunned by the majority of Silurian geologists, and their sequence has been very differently interpreted by the few who have hitherto examined them.

Of the extraordinary corrugations into which the whole of the South-Scottish Silurians are thrown it is needless to attempt any description. The rugged cliffs of the Berwickshire coast, where these convoluted rocks frown over the North Sea, have been familiar to geologists since the days of Hutton and Hall. In the inland districts we meet upon every traverse an endless succession of strata dipping constantly in the same general direction, and presenting us with the fallacious appearance of an almost interminable thickness of similar deposits.

The dominant rock of the Southern Uplands is a gritty or coarse-grained greywacke, sometimes grey or green, at other times of a deep purple colour. It is associated with beds of fissile flagstone of similar tints, which either alternate with the greywackes or occur alone in zones of great thickness. These two types of rock everywhere preponderate, and usually prevail to the exclusion of every thing else. Occasionally, however, they are relieved by masses of pebbly conglomerate, breccias, or boulder-beds; but these are very variable in character and local in occurrence.

Excluding from our present consideration the strata recognized as being unequivocally of Upper Silurian age, it is in one district only that the beds of this wide-spreading rock-group approximate in their general characters to the type familiar to us in the classic ground of Siluria. On the west coast, in the neighbourhood of the town of Girvan, limestones, shelly sandstones, and mudstones yield fossils in extraordinary profusion, and, both mineralogically and palæontologically, remind us strongly of those of the most prolific areas of Wales and Shropshire.

A fauna similar in its broader features to that afforded by the Girvan beds, but far inferior in richness and variety, characterizes the calcareous zones in the conglomerates and breccias of Peebles, Lanark, and Dumfries.

A totally distinct group of fossils, and one hitherto regarded as of little geological significance, occurs in certain beds of black carbonaceous shales and mudstones, which, in many districts, occupy long lenticular or boat-shaped areas in the great mass of barren greywacke. These peculiar beds appear quite unexpectedly and as suddenly disappear; but, when laid down upon the map, they are seen to form extended moniliform lines, often many miles in length. They are found at intervals throughout the northern half of the Uplands, from the Irish Channel to the North Sea, and everywhere swarm with Graptolites in extraordinary profusion.

The striking mineralogical features of these black bands, their prolific fauna, and their great longitudinal extent, where for thousands of square miles no other continuous stratum, separable either by lithological or palæontological characters, relieves the wearisome monotony of the interminable greywackes, soon convince the geologist that it is by their aid alone that he can ever hope successfully to unravel the more than ordinary complexity of the South-Scottish succession.

In seeking to elucidate the geological structure of the Southern Uplands, these Graptolitiferous strata naturally claim our first attention. It is impossible to clear up all the difficulties in which they are enshrouded within the limits of a single memoir. In the present paper I shall therefore restrict myself to the enumeration and discussion of such facts regarding their physical and zoological relationships as may be gathered within the single area where they are most perfectly exhibited, and which may conveniently be denominated the Moffat district.

§ II. *General Characters of the Strata of the Moffat District.* (Plate XI.)

The district included under this title is a rectangular area about 25 miles in length and 8 miles in average diameter, lying almost in the geographical centre of the South-Scottish Silurians. A small portion of the northern half of the area is included in Peeblesshire; the remainder is almost equally divided between the two adjacent counties of Selkirk and Dumfries, the line of demarcation between them running in an irregular curve transversely through its centre.

As a whole, the district may best be considered as embracing that portion of the rolling tableland of South Scotland lying immediately to the north-east of the upper reaches of the fertile vale of the Annan, which, roughly speaking, forms its abrupt western boundary. In every other direction it merges imperceptibly into the sea of rounded heights and hollows that constitute the Southern Uplands. The county boundary already referred to marks the position of the watershed between the head waters of the streams draining into the Irish Sea and those which flow into the German Ocean. This ridge includes the most elevated ground in the south of Scotland, its culminating points, White Combe, Hartfell, &c., exceeding 2600 feet in height. The burns that descend its northern slope unite to form the Tweed and its tributaries, the Yarrow and the Ettrick; those to the south are all feeders of the Annan. These numerous mountain-streams have eroded the ancient plateau into a perfect maze of narrow valleys, many of which, especially those of Blackshope, Carrifran, Gameshope, and the Talla, are bounded by abrupt or precipitous cliffs, and afford striking examples of upland scenery.

The district is cleft longitudinally through its centre, from end to end, by a deep narrow valley, along which passes the highway from Selkirk to Dumfries, forming the only means of intercommunication between its sparsely scattered inhabitants. The western half of this hollow is constituted by the picturesque pass of Moffatdale, which, bounded on both sides by a line of bold heights, runs in a perfectly straight line ten miles in length from the Annan to the watershed at Birkhill. To the east the hollow is continued by the tortuous gorge of the infant Yarrow; this, widening as it descends, embosoms the lonely lake of St. Mary's, and ultimately passes out of the district into the cultivated haughs of the more populous area of Ettrick Forest.

The lowlying flats of Annandale are formed of the relics of Permian deposits; but all the upland portions of the Moffat district are carved out of the grey, intractable Silurian grits and flagstones already so frequently referred to. Beyond a clearly marked tendency in these rocks to arrange themselves in broader and broader zones, wholly made up of one or other of these elements, as we pass over them from south to north, they are everywhere precisely similar, barren, monotonous, and uninviting.

Lying at intervals among these unfossiliferous greywackes occur thick bands of black carbonaceous shale, loaded with Graptolites, and associated with beds of barren mudstone, grey, green, purple, and occasionally pure white. These very distinctive strata run longitudinally through the district in the direction of the strike, or are exposed in long lenticular areas of small diameter. Being much softer than the greywackes amid which they repose, they are more easily destroyed by the action of the elements, and are usually eroded into narrow valleys or form the beds occupied by the smaller mountain-streams. The line of demarcation between them and the greywackes everywhere gives rise to a prominent physical feature, apparent even upon the turf-covered slopes. In the streams the divisional line is in general strikingly marked by a picturesque cascade, the water plunging over a precipice of grit into a deep black hollow, worn out of the soft mudstones below. The strata proper to the shale-bands are at once distinguished, by their colour, composition, and texture, from the rocks among which they lie; and where they cross the steeper ridges their place is marked by a deep red gash or score in the mountain-side, strongly relieved against the dark heather-clad slope, and visible at a great distance.

The black carbonaceous shales are highly pyritous, and the waters that flow through them are all more or less impregnated with sulphate of iron. The mudstones themselves and the banks of the streams for some distance below each exposure are normally stained of a deep red or bright orange-colour by the mineral deposit from the waters. The springs that rise among the shales, or are immediately derived from them, afford the chalybeate waters for which the district has long been celebrated. To the presence and efficacy of these springs is owing the material prosperity of the flourishing town of Moffat, the only place of importance in the district, and, at present, the most fashionable watering-place in the south of Scotland.

The title of Moffat Series, or Moffat Shales, by which these remarkable deposits have long been known to geologists, is thus singularly appropriate; and as these rocks attain here their fullest development, and at the same time are most satisfactorily exhibited, this title is certain eventually to supersede all others as the general name for all the Scottish graptolitiferous deposits of corresponding age.

At least four distinct bands of the dark shales are traceable to the south of the Moffat-Yarrow valley, and one of them is prolonged in a broken line far beyond the south-western limits of the district. A larger number are apparent to the north of the central valley; but in none of these are the exposures so continuous or satisfactory.

Exception being made of a narrow strip of country in the neighbourhood of St. Mary's Loch, where the strata have a southward inclination, all the rocks of the district, greywackes and mudstones alike, dip uniformly to the N.N.W. at high angles. Faults, folds, and inversions are occasionally visible among the greywackes; but in the dark shales they are astonishingly abundant. In every known locality where the Graptolitic beds are exposed, the majority are in this contorted and dislocated condition, and the attempt to ascertain their interrelationship by lithological and stratigraphical evidence has soon to be abandoned as hopeless. Their separation by zoological characters appears quite as desperate; for in many localities every trace of their former prolific fauna has been obliterated; in others only one or two fragmentary forms are obtainable, and these are limited to a few inches of thickness of the less altered zones. Even in those bands where the fossils are numerous and well preserved, the neighbouring exposures have frequently not a single fossil in common.

It is to the consideration of the numerous facts recently made out regarding the black Graptolitic shales that the present paper will be devoted. These peculiar rocks are quite as abundant in other districts, but it is here that they attain their maximum thickness and yield their most varied fauna. At the same time they are here less metamorphosed than elsewhere; and consequently here, if anywhere, will the problems they suggest admit of a satisfactory solution.

In the following pages I shall endeavour to prove that, in spite of the uninviting and, indeed, highly perplexing features of these deposits as here exhibited, we have actually within the limits of the present district more than sufficient stratigraphical and palæontological evidence to enable us to piece together the shattered fragments of this important rock-group, and in this way to fix the original sequence of its component beds, to mark out the distinguishing fossils of its various zones, to determine with certainty their geological age, and to point out their representatives in foreign countries.

§ III. *History of previous Opinion.*

It is to Prof. Sedgwick that we owe the earliest detailed notice of the rocks of the Moffat district. In his memoir "On the Geological Structure and Relations of the Frontier Chain of South Scotland" *, read at the meeting of the British Association at Glasgow in 1850, he arranged the rocks of the Southern Uplands into five successive formations. The lowest and most ancient of these formations, which he denominated the Moffat Group, embraced the majority of the strata of the present district. It was defined as "a great thickness of arenaceous rocks, in which pyritous and Graptolitiferous schist abounds to such an extent that the arenaceous beds become sometimes subordinate to it." His second group, for which he proposed no distinctive title, included the much broader mass of greywackes to the northward, apparently destitute of the aluminiferous schists.

But the most valuable and important paper hitherto published upon the rocks of the Moffat neighbourhood is the memoir by Prof.

* Rep. Brit. Assoc. 1850, pp. 103–4.

Harkness, "On the Silurians of Dumfries," presented to the Geological Society of London in 1850 *.

The author clearly recognized the fact that the pyritous shales are arranged in long lines among the barren greywackes, and gave a brief description of several localities along the three parallel bands of Hartfell, Frenchland, and Craigmichan, tracing these bands for many miles through the district, and hinting their probable extension from sea to sea. Giving a general account of their peculiar strata, their mineral character and fossils, he called especial attention to the remarkable similarity of the rocks of the three bands, pointing out at the same time their excessive convolution, fracture, and local metamorphism. From these facts he drew the most important inference that they were originally portions of one and the same deposit. Their present position he attributed to three gigantic faults running through the district parallel with the general strike of the beds. The arenaceous strata among which they are imbedded, he believed to be of the age of the Caradoc Sandstone of Siluria.

The same year Sir Roderick Murchison, in his memoir "On the Silurian Rocks of the south of Scotland" †, made several important allusions to the strata of the district, some sections of which he had himself hastily examined under the guidance of Prof. Harkness. He expressed his willingness to accept Harkness's theory of the identity of the strata forming the anthracitic bands; but preferred to interpret their geographical position on the hypothesis of great folds, the upper arches of which had been denuded. At the same time he emphatically assigned to the whole of the rocks of the district a geological position inferior to that of the Bala Limestone of North Wales. He seems to have been especially struck with their shattered and convoluted aspect, acknowledging that "all inferences drawn from physical appearances must indeed be deceptive in so tortuous and convulsed a region."

The fossils of the black bands have been subsequently figured and described by Messrs. Carruthers and Hopkinson, Prof. Nicholson, and others; and many references to the relationships and geological position of the dark shales have been published by various geologists, but no physical facts obtained within the district itself have hitherto been brought forward in support of their conclusions.

The task of determining the interrelationships of these enigmatical deposits, though in truth a very simple one, has been but slowly accomplished. The scale even of the 6-inch maps was soon ascertained to be insufficient to allow of the insertion of all the natural subdivisions of the dark shales; and they had to be supplemented by enlarged sketch plans of all the more important exposures. The caution requisite in proving and reproving every important point, stratigraphical and palæontological, in a region so excessively disturbed has necessitated the accumulation of a mass of confirmatory and supplementary evidence, sufficient to place wholly beyond cavil all the data upon which our conclusions are founded.

The determination of the geological age of the Moffat strata, and

* Quart. Journ. Geol. Soc. vol. vii. p. 46 *et seq.* † *Ibid.* vii. p. 139.

the correlation of their subdivisions with their foreign equivalents, would till recently have been practically impossible. In this connexion I have been presented with many facilities denied to former investigators. The valuable papers by Mr. Hicks on the sequence and fossils of the various subformations of the Cambro-Silurian of South Wales have been of especial service to me. From several other eminent observers I have also to acknowledge most important aid. To Mr. J. Hopkinson I am indebted for much of my knowledge of the Graptolithina of Wales. Professor H. A. Nicholson placed at my disposal the results of his researches in the Lake district. Dr. G. Linnarsson, of Stockholm, furnished me with a complete summary of the facts hitherto collected by the Swedish Survey with respect to the range of the Graptolithina in the Scandinavian Silurians. Through the kindness of the three last-named gentlemen I have been enabled to compare the organic remains of the Moffat rocks species for species with those of their extra-Scottish representatives.

Much of the district under description was worked over in company with my friend Mr. James Wilson; and my study of the fossils of the dark shales was greatly facilitated by the aid afforded me by several observers who had already made collections from these strata outside the limits of the Moffat district. Among others I have especially to thank Mr. W. Swanston, of Belfast, and Messrs. D. J. Brown and W. Dairon, of Glasgow.

A. Physical Relations of the Moffat Series.

§ I. (a) *Description of the typical Section of Dobb's Linn.* (Plate XII. Sections I., II., III.)

The only section of the Moffat Series which allows us to determine with certainty the sequence and palæontological characteristics of its component beds, and at the time clearly exhibits the relationship of the group as a whole to the surrounding greywackes, occurs in the centre of the Moffat district, about midway along the longitudinal depression already referred to. The highway from Selkirk to Dumfries, which runs upon the floor of this depression, crosses the main watershed at the spot marked by the little cottage of Birkhill, and begins to descend the long straight valley of Moffatdale to the south-west. About half a mile below the cottage three small streams of nearly equal volume meet at the same point to form the infant Moffat. Two of these streams dash down the steep slopes bounding the valley to the south-west; but as they flow over thick beds of hard grit, their courses are comparatively shallow and insignificant. The third stream, however, which descends from the north-west, emerges from a gloomy hollow dug deep in the flank of the rugged ridge that shuts in the main valley to the north.

Entering this hollow at its foot, it is seen to be a narrow rugged gorge, deriving its forbidding appearance from the black shales that close it in, and mount up on both sides in naked cliffs of great height. Near its centre it is joined by a second gorge, narrower and deeper, and terminated abruptly by a precipice of grit. Above the precipice two small streams draining the moory mountain-tops to the west unite, and hurl their waters down the cliff in two successive leaps to the bottom of the chasm, which, like the longitudinal hollow itself, has been excavated wholly in the black and grey shales of the Moffat Series.

This picturesque cascade, which is known as Dobb's Linn, gives its name to the whole glen. Like many of the deep rugged gorges that relieve the smooth undulating monotony of the Uplands, the place has its legends of the Covenanters, bloody and quaint, so that, apart altogether from its weird scenery, the spot has long enjoyed a local reputation.

To the geologist visiting the glen for the first time the section of the shales and mudstones afforded by the northern cliff of the lateral gorge is that which, above all others, commends itself to his notice, as it is visible from end to end, and, exception being made of a few local contortions, the strata exhibited appear to follow each other in natural and unbroken sequence. The coarse grits and flagstones of the falls dip at 70° or 80° to the east, and plunge visibly beneath a thick series of grey shales with black bands. This group is followed first by a group of black shales, and next by a similar thickness of greenish-grey mudstone. Upon the latter reposes a second series of black shales, much thicker, and quite distinct in its general features from that already noticed, forming clearly the final member of the Moffat Series as here exhibited, and passing beneath the greywackes of the eastern cliffs at a low angle. So clear are these facts, and so obvious the conclusions to which they point, that no one would hesitate to infer that the Moffat beds of this locality constitute a single band of fossiliferous shales and mudstones, composed of three members, and actually interbedded in the great barren greywacke series. (Plate XII. Section I.)

If, however, we select any one of the well-marked zones of black, white, or green mudstone so conspicuously exhibited at this spot, and follow it carefully in its outcrop, first up the south cliff, and thence across the face of the steep slope on the right-hand side of the longitudinal gorge, it will be ascertained that it gradually undergoes a complete reversal of its original inclination, until, finally, in a magnificent cliff-section about 100 yards from our starting-place, all the zones we have recognized in the lateral gorge, together with others not there apparent, and inclusive also of the coarse grits and flagstones of the waterfall itself, are now arranged in the opposite order, and dip steadily at a gentle angle to the W.N.W.

Thus, in the two chief sections of the glen, the order of succession deduced from the evidence afforded by the one is completely contradicted by that of the other. It is clear that in one of these sections the strata must be inverted; and we are thus taught at the very outset of our inquiry how utterly futile is the endeavour to determine the original sequence of these deposits merely by attention to their *apparent* order of superposition in any single section, however perfect.

(a) *Subdivisions, Characteristics, and Inter-relationships of the Strata exhibited in the typical section of the Main Cliff.*

The only locality in the glen where the junction of the greywackes with the dark shales and mudstones is distinctly visible for some distance is in the floor and sides of the lateral gorge immediately below the falls (Plate XII. Sect. I.). Here the sequence from the greywackes for at least 100 feet into the very heart of the Moffat beds is seen to be unbroken; and the evidences afforded by the bed of the stream can be easily checked and supplemented at every stage of our inquiry by a comparison with the frequent exposures of the same strata in the South Cliff, in the floor and walls of the steep "corrie" to the north-west, or along the bottom of the little rill that trickles down its centre.

Commencing with the greywackes of the falls, which, dipping to the south-east at a very high angle, visibly pass below all the mudstones and shales of the glen, and reading off the characters of the consecutive beds in what thus appears to be the ascending order, we note the following succession (Vertical Sect. fig. 1, p. 250):—

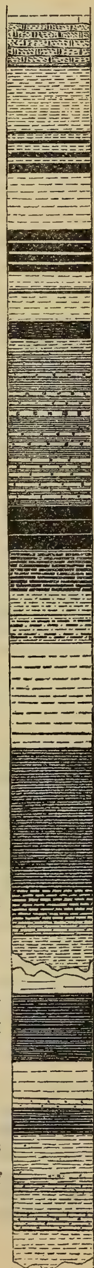
(I.) *First or Birkhill Division.*

(i.) *First Grey-Shale Group.*

ft.

1. Grey and greenish shales and flaggy beds.......................... 15
2. Grey shales containing four black bands, from 2 to 4 inches in thickness, and occasional laminæ of soft shaly clay of a pure white or cream-colour. Graptolites are numerous in the black seams. The most characteristic forms are *Rastrites maximus* (Carr.), *Monograptus Halli* (Barr.) 10
3. Grey shales with white-clay bands, barren of fossils 15
4. A peculiar assemblage of black, white, and greyish-brown shales and mudstones. Some of the dark mudstones are soft and highly pyritous. A few thin seams are sandy and harsh to the touch. The latter are sometimes cut up superficially into lozenge-shaped reticulations by a series of shallow grooves, somewhat resembling sun-cracks, but always perfectly straight throughout. 10
   Fossils are abundant in the darker beds. The most prevalent forms are *Monograptus Sedgwicki* (Portlock)=*M. spinigerus* (Nich.) and *Monograptus Hisingeri* (Carruthers).
5. Grey mudstones, with seams of white clay 15
   Near the middle of this band occurs a thin seam of black shale, which is well shown at the head of the Corrie. It is about 6 inches in thickness, and is charged with *Monograptus Clingani* (Carr.) and *Rastrites hybridus* (L.). Immediately below the fossil-bed in this section is a curious seam of dark grey mudstone, covered with the trains of Annelides, and full of small nodular concretions.
6. Zone of highly pyritous black shale, disintegrating into small flaky fragments, which are coated with a rusty film of iron oxide, or flowers of alum. It is crowded with poorly preserved specimens of *Monograptus lobiferus* (M'Coy), *Diplograptus cometa* (Gein.) 8
   This is covered by 4 feet of barren grey shale, above which follow the first beds of the succeeding black-shale group.

Fig. 1.—*Vertical Section, showing the Subdivisions of the Moffat Series of Dobb's Linn and Craigmichan Scaurs.*



Gala or Queensberry flagstones and Greywackes.

No fossils.

Birkhill Shale.

Upper Birkhill.

*Cb*³. Zone of *Rastrites maximus* (Carr.). Grey flaggy shales, sometimes purple, containing four seams of dark carbonaceous shale with fossils. — *Rastrites maximus, Monograptus turriculatus, M. proteus, M. involutus, M. intermedius, M. runcinatus, M. Becki, Peltocaris aptychoides.*

No fossils.

*Cb*². Zone of *Monograptus spinigerus* (Nich.). Black and grey shales, with seams of white clay. — *Monograptus spinigerus* (= *Sedgwicki*), *M. Hisingeri, M. tenuis, M. attenuatus, Diplograptus Hughesi, Retiolites perlatus, Rastrites hybridus, R. capillaris.*

Horizon of *Monograptus Clingani.*

*Cb*¹. Zone (sub-) of *Diplograptus cometa* (Geinitz). Black and grey shivery mudstones. — *Diplograptus cometa, D. sinuatus.*

Lower Birkhill.

*Ca*³. Zone of *Monograptus gregarius* (Lapw.). Black flaggy shales, with lines of coloured clays and seams and nodules of iron-pyrites. — *Monograptus leptotheca, M. lobiferus, Rastrites peregrinus, Diplograptus tamariscus, Discinocaris Browniana, Eurypterus,* &c., *Monograptus fimbriatus, M. argutus, M. triangulatus, M. Sandersoni, M. communis, M. concinnus, M. cyphus, Diplograptus palmeus, D. physophora.*

*Ca*². Zone of *Diplograptus vesiculosus* (Nich.). Hard black carbonaceous flags. — *Diplograptus vesiculosus, Climacograptus innotatus, Monograptus tenuis, M. attenuatus.*

*Ca*¹. Zone of *Diplograptus acuminatus.* Shivery shales—black, brown, and yellow. — *Diplograptus acuminatus, Dimorphograptus elongatus. Climacograptus scalaris.*

Hartfell Shale.

Upper Hartfell.

*Bb*². Zone of *Dicellograptus anceps* (Nich.). Soft green shales, with seams of black and white mudstones. — *Dicellograptus anceps, Diplograptus truncatus. Climacograptus bicornis.*

*Bb*¹. "Barren Mudstone." Light green flaggy mudstones. — No fossils.

Dicellograptus, Diplograptus.

Lower Hartfell.

*Ba*³. Zone of *Pleurograptus linearis* (Carr.). Hard black slaty shales, with seams of white mudstone. — *Pleurograptus linearis, Amphigraptus divergens, Leptograptus flaccidus, Diplograptus quadrimucronatus, Dicellograptus elegans.*

*Ba*². Zone of *Dicranograptus Clingani* (Carr.). Hard black flags and slaty shales. — *Eurypterus?, Siphonotreta micula, Acrotreta Nicholsoni, Dicellograptus Forchhammeri, D. Morrisi, D. moffatensis, D. caduceus, Dicranograptus Clingani, D. ramosus, D. Nicholsoni, Retiolites fibratus, Climacograptus caudatus, Dictyonema moffatensis.*

*Ba*¹. Zone of *Climacograptus Wilsoni* (Lapw.). Flaky shales and mudstones—black, brown, and spotted. — *Climacograptus Wilsoni, C. Scharenbergi, C. bicornis, Diplograptus tricornis, D. foliaceus, Glossograptus Hincksi, Lasiograptus Harknessi.*

Glenkiln Shale.

Upper Glenkiln.

Ab. "*Didymograptus*-beds." Highly pyritous slaty black shales and flags, with beds of pale shivery mudstones. — *Cœnograptus gracilis, C. surcularis, C. pertenuis. Didymograptus superstes. Dicellograptus divaricatus, D. sextans. Dicranograptus formosus, D. ziczac, D. Nicholsoni. Diplograptus dentatus, D. Whitfieldi.*

Thamnograptus typus. Clathrograptus cuneiformis.

Lower Glenkiln.

Aa. "Ribbed Mudstones." Thick beds of pale non-fossiliferous mudstone, with seams and ribs of hard grey flags. — No fossils.

In this section consequently the first grey-shale group attains a collective thickness of about 77 feet. If we connect each of its non-fossiliferous bands with the special Graptolitiferous seams immediately above, the whole group may be regarded as falling into three distinct zones. The first of these zones is marked by the exclusive presence of *Rastrites maximus*, the second by that of *Monograptus spinigerus* and the third by the preponderance of *Diplograptus cometa.*

Next in importance to the very distinctive aspect given to the group as a whole by the alternation of broad bands of grey and black shale, the most striking mineralogical feature is formed by its intercalated seams of white clay or mudstone. These characteristic beds vary in thickness from an inch to a foot, and, when weathered, break up into small flakes about the size and thickness of a finger-nail. These clay bands abound in the South Cliff and in the walls of the corrie; their thin chaff-like fragments are scattered over the whole section of the grey-shale group, giving it a most peculiar appearance, and effectually distinguishing it from all the remaining beds exposed in the lateral gorge.

(ii.) *First Black-Shale Group.*

Continuing our catalogue of the rocks of the glen, we notice that the grey-shale group is followed by a thick series of black shales, crowded with fossils, and arranged in the following order:—

(*a*) A mass of black flaggy shales and mudstones 30 feet in thickness. In the first half of this zone the beds are thin, soft, and highly pyritous; the remainder are hard and flag-like. Throughout the whole mass there occur at intervals seams of blue, yellow, or orange-coloured mudstone or clay, varying from a few inches to nearly a foot in thickness. Many of these brightly coloured beds contain lines of calcareous concretions and balls of nodular iron-stone. One very large band of nodules occurs in the very centre of the zone, dividing it into two portions, lithologically and palæontologically distinct.

The characteristic fossil of the whole zone is *Monograptus gregarius* (Lapw.). Its first division is marked by the exclusive presence of *Rastrites peregrinus,* and the second by that of *M. Sandersoni.*

These beds, after a slight contortion in the walls of the corrie, are cut off abruptly from the strata which naturally follow them by a north and south fault, crossing the line of strike of the rocks at a small angle, and bringing them against a great thickness of pale unfossiliferous mudstones to be described in the sequel.

Leaving the lateral gorge at this point, and examining next the beautiful section in the Main Cliff (Sect. II. Plate XII.), we notice that the grey-shale group of the corrie crosses the cliff immediately below its highest point. It is in such a position that it cannot be reached with safety, but the grey, black, and white bands are easily identified from below. Instead of lying upon the coarse grits of the falls, as in the lateral gorge, it here visibly passes underneath them at an angle of about 45°.

Immediately below the grey shales lies the thick series of black shales already described, forming the first division of our first black-shale group. Its coloured and nodular bands can be seen crossing the cliff below the grey shales, and all its characteristic fossils can, by the exercise of ordinary caution, be collected along the edge of the cliff.

These beds are here underlain by the strata missing from the lateral gorge, viz.:—

(*b*) A zone of black flags, in beds of about 1 foot in thickness. These rocks are remarkably resistant of atmospheric influences, and form a jutting ledge running across the face of the cliff, overhanging and protecting from degradation the more tractable beds immediately below.

Fossils are abundant, but of few species. The commonest form is the strange *Diplograptus vesiculosus* (Nich.), which, usually associated with *Climacograptus scalaris* (His.), swarms in extraordinary profusion in some of the beds.

(*c*) The hard *D.-vesiculosus* beds repose upon a similar thickness of finely laminated black shales, weathering down into thin flakes of a pale yellow colour. They contain a smaller proportion of carbonaceous matter than the overlying beds, and are softer and less fossiliferous.

They are characterized by the exclusive presence of *Diplograptus acuminatus* (Nich.).

The lowest band of this zone is very peculiar. It consists of about a foot of tough slightly calcareous shale, weathering of a dark brownish drab, or gingerbread-colour, and affording numerous examples of *Climacograptus scalaris* in a state of high relief.

At this point a sudden and most extraordinary change takes place in the genera and species of the fossils of the Moffat Series. Scarcely a single form of those collected by us in the strata already described is met with in any of the beds below this line, which are, however, like those above it, linked together by a large community of organic forms. Here, therefore, is the chief palæontological break in the succession, and here, consequently, are we compelled to draw our main line of demarcation in any natural classification of the Moffat Series of this locality.

The palæontologist who makes a detailed study of the fossils of that portion of the Moffat Series already passed under review will soon assure himself of the fact that each species and variety of Graptolite &c. has a definite range in the vertical succession of strata. None pass from the lowest to the highest zone; a few run up through the majority of the beds; several are common to two or three subdivisions; and the remainder are restricted to even narrower limits. Some (and these are the most valuable for our present purpose) are strictly confined to one or other of the mineralogical zones we have indicated above.

Further, it will be ascertained that the most prevalent forms in these beds belong to the unilateral genera *Monograptus* (Geinitz) and *Rastrites* (Barr.) of the family of the Monograptidæ. Below our great divisional line their place is taken by the bilateral genera *Dicranograptus* (Hall) and *Dicellograptus* (Hopk.) of the very distinct family of the Dicranograptidæ.

The beds above this separating line, which thus compose the first natural division of the Moffat Series as here displayed, I distinguish by the title of the Birkhill Shales, after the name of the watershed in the immediate neighbourhood.

(II.) *Second or Hartfell Division.*

A single glance at the strata that underlie the Birkhill Shales of the Main Cliff, and thus constitute the second provisional division of the Moffat Series, is sufficient to assure the geologist of the fact that, like the beds of our first division, they fall naturally into two very distinct lithological groups. The higher of these groups is made up of 50 feet of green, grey, and brown shales and mudstones, with a few intercalated lines of black shale, and the lower of 45 feet of hard black slaty shales and flagstone.

The upper group of pale mudstones is, again, clearly formed of two distinct subdivisions, viz. :—

(*a*) A superior zone of soft green, yellow, white, and black mudstones. The black lines in the mudstones swarm with badly preserved examples of *Dicellograptus anceps* (Nicholson).

(*b*) An inferior zone of pale greenish-grey flaggy mudstones, about 30 feet in thickness, totally devoid of fossils except in a small line about 2 inches in depth near its base.

The inferior, or black-shale group may most conveniently be regarded as composed of three zones :—

(*a*) The highest zone is formed of hard black slaty shales, varied by thin cream-coloured seams of white mudstone. Fossils are abundant, the most characteristic being the peculiar *Pleurograptus linearis* (Carr.).

(*b*) The middle zone is formed of similar hard black shales, but it includes several bands of tough siliceous black flags, about 2 inches in thickness, while the white seams of the zone last described are absent throughout.

The characteristic fossil is *Dicranograptus Clingani* (Carr.).

(*c*) The lowest zone is composed of dark greyish-black flagstones and shales totally destitute of fossils except in three or four thin seams, where they occur in a state of exquisite preservation.

The most abundant species is *Climacograptus Wilsoni* (Lapw.).

This second division of the Moffat Series is denominated the Hartfell Shales, after the locality where its beds are most perfectly exhibited, which will be described in detail in the next portion of this paper.

(III.) *Third or Glenkiln Division.*

The Birkhill and Hartfell Shales include the whole of the beds exposed in the Main Cliff, with the exception of a narrow wedge of dark flagstones, 15 feet in thickness, visible at its south-west corner.

The strata referred to are, many of them, highly siliceous, and weather down into small cuboidal fragments. Fossils are not uncommon in the partings of soft black mudstones. The most distinctive are *Thamnograptus typus* (Hall) and *Didymograptus superstes* (Lapw.).

It will be shown in the sequel that these beds appertain to a third division of the Moffat Series. To this division I have given the title of the Glenkiln Shales, from the spot where it yields its characteristic fossils in the greatest abundance.

Summary.

Disregarding for the present the small patch of Glenkiln Shales last described, it is evident that the strata of the Moffat series exhibited in the Main Cliff of Dobb's Linn are naturally arranged in two main divisions palæontologically distinct. Each of these divisions, again, falls naturally into two well-defined mineralogical subdivisions, each of which is, in turn, composed of several subordinate bands or zones, individually distinguishable by peculiar lithological and palæontological features. Arranging the strata in the order in which they are here displayed, and distinguishing each band by its predominant or peculiar fossil, we have the succession given in the following Table:—

III. Birkhill Shales.	*Upper Birkhill* or Grey-Shale Group.	Zone of *Rastrites maximus*, Carr. Zone of *Monograptus spinigerus*, Nich. Subzone of *Diplograptus cometa*, Gein.
	Lower Birkhill or Black-Shale Group.	Zone of *Monograptus gregarius*, Lapw. Zone of *Diplograptus vesiculosus*, Nich. Zone of *Diplograptus acuminatus*, Nich.
II. Hartfell Shales.	*Upper Hartfell* or Barren-Mudstone Group.	Zone of *Dicellograptus anceps*, Nich. Zone of "Barren Mudstone."
	Lower Hartfell or Black-Slate Group.	Zone of *Pleurograptus linearis*, Carr. Zone of *Dicranograptus Clingani*, Carr. Zone of *Climacograptus Wilsoni*, Lapw.
I. Glenkiln Shales.		

(b) *Section along line* A–B. (Plate XII. Sect. I.)

With this provisional key to aid us, we proceed next to test its accuracy by endeavouring to work out therewith the physical arrangement of the Moffat Series of the main body of the glen.

Returning to the lateral gorge beneath the falls, the section of the North Cliff is resumed at the point where we left it, *i. e.* at the north and south fault, by which the *M.-gregarius* zone of the Birkhill Shales is brought into contact with the great band of barren mudstone. The North Cliff itself is divided into four distinct ridges by three deep bays or "scores." The fault referred to runs up the centre of the western score. Following its direction carefully up the face of the cliff, it is seen to cut the line of strike of the beds at a very acute angle; and the lower zones of the Birkhill Shales, wanting in the floor of the lateral gorge, come in visibly one by one on the western side of the fault.

The *M.-gregarius* zone seen in the burn is followed in the cliffs immediately by the zone of hard thick-bedded black flags with *Diplograptus vesiculosus*. Here, exactly as in our type section of the Main Cliff, these flags form the most prominent portion of the slope, overhanging and protecting the subjacent and softer beds. The *D. vesiculosus* band is followed in turn by the zone of *D. acuminatus*, with its shivery shales of greyish black, and the peculiar calcareous brownish gingerbread-coloured band at its base, swarming with the same exquisitely preserved fossils.

Upon the drab line reposes the green-shale band, of about 6 feet in thickness, that constitutes the upper portion of the *D.-anceps* zone of the highest Hartfell Shales of the Main Cliff; and next follows the fossiliferous portion of the *D.-anceps* zone itself. The latter forms the north-west wall of the upper part of the West Score, and is crushed up in a sharp fold against the fault, which probably dies out a few feet beyond. Not many of the fossils of the *D.-anceps* zone are procurable from the smashed beds, but quite sufficient to show that they are identical with those of its prototype in the Main Cliff.

Crossing the line of fault, an apparent thickness of 60 or 70 feet of barren green mudstone is passed over in the North Cliff and the bed of the stream, a thickness it is very difficult to reconcile at first sight with the 30 feet of the same rock as exposed in our typical section. A careful attention to the lithological characters of the beds, however, soon reveals the fact that this excessive thickness is due to folding. Near its southern termination we recognize the thin black fossiliferous line of the band, here repeated two or three times.

Next in order comes the thin-bedded slaty-shale zone (*Pleurograptus linearis*), forming the highest subdivision of our *Lower Hartfell* Shales, the line of junction between it and the very differently coloured mudstones of the preceding zone forming a long straight line up the face of the North Cliff. The beds of this zone form a prominent portion of the summit, and yield all its fossils in abundance.

These beds are succeeded in the cliff by the *D.-Clingani* zone of hard black slaty shales. At the top of the cliff they are beautifully exhibited (but in a highly-contorted condition) near the head of the East Score, and are prolonged in some rugged bosses of black rock that protrude through the turf much further to the north. The distribution of their included fossils, *Dicellograptus Forchhammeri*, *D. caduceus*, *Dicranograptus ramosus*, *D. Clingani*, &c., makes it certain that these convoluted beds are portions of one and the same thin zone.

Up to this point, then, it is perfectly clear that the succession among the beds in the North Cliff, from the greywackes of the falls to the Lower Hartfell Shales, is identical in every respect with that in our typical section of the Main Cliff. Here, however, the strata are reversed in position, and their relations are complicated locally by visible faults and convolutions.

Continuing our section beyond the zone last described, we come immediately upon beds of a totally distinct character from any of the Hartfell Shales. These strata constitute a band of hard thick-bedded black flags, forming the highest ledge of the Long Cliff, and standing up almost on end like a broad wall. Their appearance and behaviour instantaneously call to mind the conspicuous *D.-vesiculosus* bands of the Birkhill Shales; and their identity with them is soon placed beyond question by the detection of numerous examples of *Diplograptus vesiculosus*, and its constant associates *Climacograptus innotatus* and *Monograptus tenuis*.

Between this band and the thin-bedded *D.-Clingani* zone of the summit of the cliff must necessarily occur a fault of some magnitude, as almost all the Hartfell shales, and several of the Birkhill zones, are missing from between them. This, as we shall presently ascertain, is a portion of the most important fault in the rocks of the glen.

At the eastern foot of the wall formed by the *D.-vesiculosus* band lies the shivery *D.-acuminatus* band, dipping below the former in the same attitude as in the Main Cliff. It swarms with its characteristic fossils, and affords several excellent exposures of the peculiar gingerbread-coloured bed at its base.

This zone reposes immediately upon the six-foot mudstone of the *D.-anceps* zone, which forms a pale band running obliquely up the Long Cliff for some distance, very conspicuous among the dark shales by which it is surrounded. It is underlain in its turn by the fossiliferous and variegated portion of the *D.-anceps* band, admirably exposed, and swarming with *Dicellograptus anceps*, *Climacograptus tuberculatus*, &c.

Between this point and the great fault at the summit of the cliff these three zones of *D. vesiculosus*, *D. acuminatus*, and *Dicellograptus anceps* are arranged in the same order as in the Main Cliff, and have a corresponding dip to the west. But passing upwards beyond the *D.-anceps* zone the sequence becomes greatly confused; the rocks are so convoluted and shattered that any attempt to unravel them along this line appears a well-nigh hopeless task. These contorted beds are clearly crushed against a line very slightly transgressive upon the *D.-anceps* zone, which itself everywhere retains the steady strike and dip of the pale mudstone band immediately above it. It is therefore highly probable that we have here a third line of fault, running generally along the base of the *D.-anceps* zone.

That this is actually the case is proved at once upon an examination of the succeeding contorted beds. Everywhere to the north and south of our line of section they show the characteristics of the *M. gregarius* zone of the Birkhill Shales—the red, blue, and yellow seams of clay, the peculiar lines of nodular concretions, together with swarms of the distinctive fossils, *M. gregarius*, *Rastrites peregrinus*, *Diplograpsus tamariscus*, &c.

This fault can be traced from a point near the centre of the upper edge of the Long Cliff, down the base of the *D.-anceps* zone into the Long Burn, at a point near its lower termination. The contorted *M.-gregarius* beds which bound it on the east form the whole of the Long Cliff, below the fault, from end to end, for a distance of about 300 yards. Towards the north the contortion gradually decreases in intensity till near the upper extremity of the gorge, where we have a complete confirmation of our reading of the cliff-structure. Here the *M.-gregarius* zone we have traced upwards shows all its component strata dipping in regular (but inverted) order, and yielding its peculiar fossils in a finer state of preservation than anywhere else within the limits of the glen. It passes down gradually, bed upon bed, into the conspicuous *D.-vesiculosus* zone, the thick flaggy strata of which form the steep walls of the head of the gorge, and expose beyond them traces of the shivery *D.-acuminatus* zone, and of some pale-green strata that may belong to the Barren Mudstone.

To complete our section we have finally to ascertain what are the beds that lie between the contorted *M.-gregarius* zone of the Long Cliff and the grits and flagstones that are visible occasionally along the upper edges of the East Cliff, forming the boundary of the Moffat Series in that direction. Unfortunately immediately in our line of section the required beds are almost wholly obscured by turf and talus. At one spot, however, near the centre of the Long Burn, where it commences its north-westerly curve, several of the beds of which we are in quest are shown in a fine cliff-section. They are seen to consist of thin bands of grey shales and mudstones, with here and there a thin black line. Among them occur several seams of pure white clay, weathering into small flaky fragments, which are scattered over the whole section, and give it a most peculiar appearance when viewed at a little distance. It is impossible to doubt for a moment that we have before us the first Grey-shale group, or Upper Birkhill Shales of the waterfall, which, however, instead of reposing upon the greywackes, actually pass beneath them at a low angle. The few fossils procurable, which include *Monograptus spinigerus* (Nich.), *M. Hisingeri*, and *Diplograptus Hughesi*, distinctly confirm this conclusion, as also does the fact of the presence of the hard grey band forming the base of the group, which is seen running from side to side of the bed of the little stream immediately below. A little further to the north, and in the contorted beds above, several additional Upper Birkhill Graptolites are obtainable.

Beds belonging to the same set of grey and black shales crop out at intervals along the whole remaining length of the East Cliff below the greywackes, between the latter and the contorted zone of *M. gregarius*; and their precise identity with those of the grey group of the corrie is placed wholly beyond doubt when the several exposures are examined in detail, the sequence of the various bands agreeing with those of the latter in every respect.

The study of this section of the North Cliff has taught us that in the upper portion of the glen there are no black shales present that do not belong to the Moffat Series, as exposed and tabulated in our typical section of the Main Cliff; and, further, that as the zones in contact with the greywackes at both ends of the section are identical, although they dip in the same direction, it is clear that we have here a faulted anticline or syncline, the axis of which is inverted.

(c) *Description of the Section along line* C–D. (Plate XII. Sect. II.)

This section crosses the Main Cliff near its southern extremity, at right angles to its general direction. Its western half is made up of the strata enumerated in our typical section, and the total exposure of the Moffat Shales along its course is reduced to a little more than half the diameter of that on our former traverse.

Commencing at the summit of the Main Cliff, the coarse greywackes of the falls are seen dipping at a gentle angle to the west, off the Grey-shale group; and, descending the line of section, the various strata of the Birkhill, Hartfell, and Glenkiln divisions, as tabulated, are passed over in orderly succession. Thrust abruptly against the patch of Glenkiln Shales in the southern angle of the cliff, and dipping generally in the same direction, are some contorted grey and black bands yielding a few fragments of Birkhill forms. These become more numerous in some bosses of hard, flaggy, and contorted black shale, through which the stream cuts its passage, and include *D. vesiculosus*, *D. tamariscus*, and *M. gregarius*. The presence of some nodular and coloured clay bands at this spot are an additional evidence that these beds belong mainly to the *M.-gregarius* zone. This is at once proved to be the case if we follow them in their course along the east bank of the stream to the northward, where in a naked portion of the East Cliff, a short distance below the foot of the Long Burn, they are exhibited in a magnificent exposure. Every characteristic of the *M.-gregarius* zone is here apparent, the large central nodule-band being especially conspicuous among the contorted strata, and the special fossils obtainable in great profusion.

Between this contorted zone (which is visibly the southerly continuation of the contorted *M.-gregarius* zone of our former section) and the wedge of Glenkiln Shales at the foot of the East Cliff must therefore be a fault cutting out the whole of the Hartfell Shales. A glance at the map (Pl. XI.) will show that this is the southerly continuation of the main fault of the North Cliff detected in our former section.

Reposing upon this contorted *M.-gregarius* zone, and passing below the greywackes that form the higher portion of the East Cliff, are the grey and black bands of the *Upper Birkhill Series*. They are exposed only in fragmentary patches in some of the numerous scores that furrow the talus-covered slope; but, as already mentioned, the zones of *M. Sedgwicki* and *M. cometa* are plainly discernible, and the characteristic white-clay bands may be detected everywhere among them on clearing away the overlying *débris*.

Thus on both sides of this section the thick barren greywackes and flagstones of the surrounding country are the highest beds, and they are in both cases immediately underlain by the Grey-shale group of the Birkhill Shales, which in its turn is supported by the nodular or *M.-gregarius* zone.

We are furnished in this way with a complete and convincing reply to the question left unanswered by the evidence of our previous sections. We have now no choice but to regard the Moffat Series in the glen as being arranged in an anticlinal form; and at the same time the sequence of its component beds, as displayed in our typical section of the Main Cliff, is thus demonstrated to be the natural order of succession.

(d) *Physical Structure of the Glen.*

We are now able to comprehend fully the physical arrangement of the strata exposed within the Glen. The Moffat Series of this locality, is disposed in the form of a rude arch, which is broken by three longitudinal faults. In the centre of the Glen the plane of the main axis of the anticlinal is approximately perpendicular, and the beds are shown in their natural position. To the northward the axis dips to the eastward, and the strata upon its western side are all inverted. In the southern portion of the Glen, on the other hand, the axis dips to the westward, and it is the eastern beds which are overturned.

The central or main fault runs along the crown of the anticlinal from end to end. At its southern (visible) extremity it brings together the very lowest beds of the locality—the Glenkiln Shales—and the highest zone of the Hartfell division. As it passes to the northward it cuts obliquely across the *Glenkiln* beds and the lowest zone of the Hartfell Shales, and brings them into unnatural collocation with the variegated beds of the inferior portion of the Birkhill division.

The eastern fault runs approximately parallel to the central dislocation, letting in a long thin wedge of Upper Hartfell and Lower Birkhill beds between the main fault and the convoluted Upper Birkhill beds of the eastern cliff.

The western fault is of least importance. It is about 200 yards in length, attaining its maximum effect near its centre, where the truncated ends of the lower zones of the Birkhill Shales are seen in contact with the Barren Mudstones.

These three dislocations are all of the puzzling class known as inverted faults—the hade being towards the *upthrow* side of the break. Faults of this nature are numerous everywhere in the Moffat rocks; but the geologist is exceptionally fortunate in this district in the fact that the sections on the opposite sides of the break are easily interpreted, owing to the unmistakable characteristics of their component zones. These faults are miniature representatives of the gigantic dislocations of the Alleghanies of Pennsylvania and the Alpine regions of Europe. They resemble those of the latter area still further in the interesting circumstance that we have some examples of the well-known "fan-shaped" structure. In the Moffat district this is usually due to the fact that wedges of the inferior Glenkiln and Hartfell Shales have been pressed upwards, in the direction of least resistance, between converging walls of the naturally overlying Birkhill and Gala beds, which have been forced inwards upon them from opposite sides by the excessive lateral pressure.

The section of the North Cliff in the present locality is a good instance of this phenomenon. The Birkhill Shales, which bound the central wedge of Hartfell Shales &c. included between the converging east and west faults, have been thrust inwards upon the lower and narrower portion of the wedge, forcing it upwards, and at the same time giving its component strata the characteristic radiating dip.

§ I. (B) *Description of the confirmatory sections of Craigmichan Scaurs.* (Plate XIII. Plan A.)

Before applying the results deduced from our study of the rocks of Dobb's Linn to the investigation of the shattered beds of the Moffat Series exposed along the various lines of black shale, it will be more satisfactory if we first put them to a crucial test by endeavouring to unravel at least one additional section in which the whole sequence of the beds is exposed. The only section suited for this purpose is that of Craigmichan Scaurs, which occurs on the western flank of Capel Law (2300 feet) at the head of Selcoth Burn, a small stream falling into the Moffat water about six miles below Birkhill.

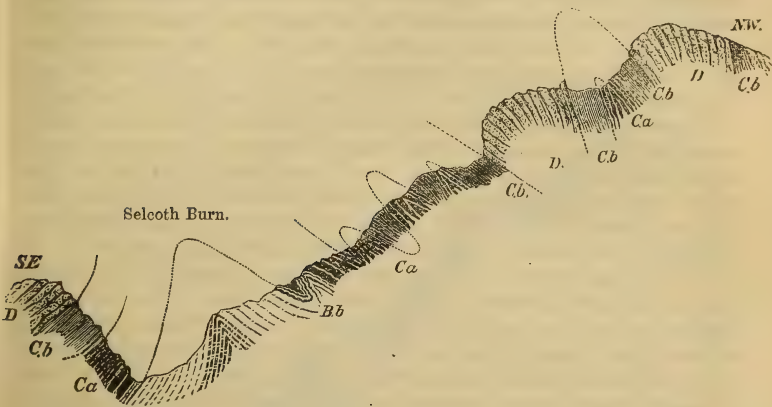
The rocks of the Moffat Series at this locality are shown in a remarkably rugged gorge, about a mile in length, bounded on both sides by steep slopes, partly formed of naked cliffs of black shales, partly of mounds and trails of their weathered fragments. The southern wall of the gorge resembles that of Dobb's Linn. It is black and precipitous, but nowhere reaches a hundred feet in elevation. The northern wall is actually the flank of the mountain of Capel Fell, and shows a naked and almost vertical face of dark shale and mudstone, five hundred feet high, affording the most magnificent section of the Moffat Series in the south of Scotland.

Everywhere within the gorge itself appear the black and variegated Moffat Shales. On the higher portions of the bounding cliffs are seen the thick greywackes and flagstones of the Gala group. At one spot the latter visibly descend the southern cliff for some distance, affording us an excellent starting-point from which to commence a study of the succession.

(a) *Section along line* A–B. (Fig. 2.)

Immediately we descend into the dark shales below the greywackes, we observe at a glance that we have no longer to deal with slightly disturbed and highly fossiliferous beds like those of Dobb's Linn, but with strata contorted and shattered, and so greatly altered that their fossils are almost wholly obliterated. Here and there, however, we observe certain grey bands with white lines dipping below the grits; and searching carefully right and left in the less disturbed patches we detect the following species:—*Monograptus spinigerus* (Nich.), *M. Halli*, *Rastrites distans* (Lapw.), and *M. Hisingeri* (Carr.), all of which are strictly peculiar to the grey group or Upper Birkhill Shales of Dobb's Linn.

Fig. 2.—*Craigmichan Scaurs.* (Lower Section.)



D. Flagstones and greywackes of the Gala group.
Cb. Grey shales with black and white seams, contorted. *Rastrites maximus*, *Monograptus spinigerus*, *Diplograptus cometa*, &c.
Ca. Black carbonaceous flags and shales, with *Rastrites peregrinus*, *Monograptus gregarius*, *Diplograptus vesiculosus*, &c.
Bb. Pale mudstones and shales, non-fossiliferous.

In the beds immediately below no fossils are visible; but if we examine them in their extension higher up the stream, we see that they include the coloured lines of the *M.-gregarius* bands, together with some of the hard flag-like beds of the *D.-vesiculosus* zone; and yield in abundance such characteristic forms as *D. vesiculosus* (Nich.), *D. tamariscus* (Nich.), *D. palmeus* (Barr.), *M. gregarius* (Lapw.), *Rastrites peregrinus* (Barr.), &c.

This completes the section of the southern cliff. Crossing the bed of the stream and commencing the ascent of the northern slope, we pass over a great group of barren shales and mudstones of a greyish-brown colour, clearly the "Barren Mudstone" of our typical section, here, however, showing no trace of the fossiliferous *D.-anceps* seams. They are apparently nearly a hundred feet in thickness, more than twice that of their prototypes of Dobb's Linn. The cause of this is soon evident, as they are seen to be arranged in a sharp anticline, the axis of which is inverted, dipping slightly to the north-west.

To the Barren Mudstone succeeds a great mass of the Lower Birkhill Shales, much broken and twisted. It reposes upon the preceding zone at a low angle, exhibits the peculiar variegated mudstone lines, and yields an abundance of characteristic fossils. It subsides in its turn below a shattered group of grey and black beds with white lines, affording *M. spinigerus*, *R. hybridus*, &c., the distinctive Graptolites of the Upper Birkhill Shales.

These finally plunge below a thick group of greywackes and flagstones, forming the upper portion of the cliff, and continued in a prominent series of bosses projecting along the hill-face to the right and left. The grits occupy about 100 feet of the section, and are visibly arranged in a synclinal form, the inverted axis of the fold dipping into the hill at an angle of about 40°. Beyond them the dark shales rise again to the surface in a hollow notch on the face of the steep slope above the actual summit of the cliff. The fossils of these shales are intermingled in the *débris* of the hollow; they are all of species peculiar to the Birkhill division. This notch shows at its summit the grey bands of the Upper Birkhill, which for the third time visibly pass below a superior mass of greywackes and shales. These form the small peak of the hill-top and are continuous with the great sheet of greywackes of the surrounding country.

It is obvious therefore that along this line of section the rocks of this locality are arranged in two main anticlinals. The strata exhibited range from the greywackes down into the Barren Mudstone of the Upper Hartfell Shales. Within these limits (exception being made of the apparent absence of the fossiliferous portion of the *D.-anceps* band), the sequence of rocks and fossils is precisely similar to that in our typical section of Dobb's Linn.

(b) *Description of the Section along line* B–D. (Fig. 3.)

Before we are able fully to comprehend the physical arrangement of the whole of the rocks exhibited within the Glen, it will be necessary to make a second traverse of the beds from the summit of the southern cliff along its southern margin.

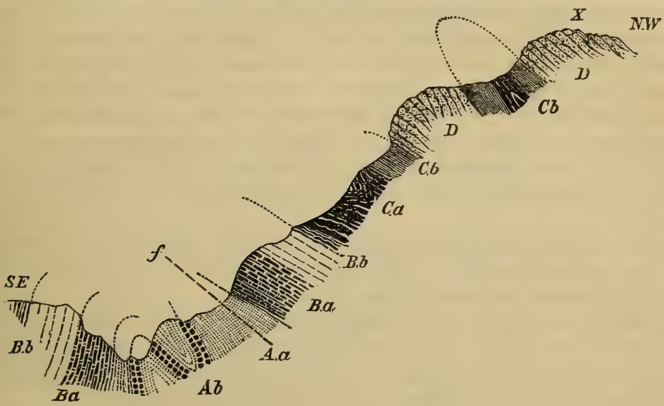
Descending the slope in a south-westerly direction from the point *X*, we pass over in succession the bands of grit and Birkhill Shales noticed in our former section to the line of the barren mudstone. This passes in a wide and very conspicuous pale-grey band transversely across the whole face of the cliff, reaching its southern edge at a point near the centre.

In our previous section this was the lowest bed exhibited. Here, however, we find a great thickness of subjacent strata. It is immediately underlain by a group of thin-bedded shales about 10 feet in total thickness, showing numerous white bands, especially in the upper part, and swarming with *D. Morrisi* (Hopk.), and *Pleurograptus linearis* (Carr.), thus agreeing exactly in stratigraphical position, mineralogical character, and fossils with our *P.-linearis* zone of Dobb's Linn.

This reposes upon a thickness of about 30 feet of contorted black flaggy shales with fragments of *Corynoides calycularis* (Nich.) and *Dicellograptus Forchhammeri* (Geinitz) in its upper beds, and showing at its base the hard thick-bedded and more siliceous bands of the *C.-Wilsoni* zone.

The remainder of the cliff down into the bed of the stream is occupied by strata wholly distinct in their general characters from any thing we have hitherto recognized in this locality. They consist of soft sandy mudstones, bluish grey, yellow, or even of a pure white, somewhat concretionary where unaltered, and reminding us strongly of ashy shales where indurated and slightly metamorphosed. With these are associated bands of hard siliceous rock, compact, ringing under the hammer, and weathering into cuboidal fragments.

Fig. 3.—*Craigmichan Scaurs.* (Upper Section.)



D. Greywackes and flags of the Gala group.
Cb. Grey shales, with *Rastrites maximus*, &c.
Ca. Black flags, with *Monograptus gregarius* and *Diplograptus vesiculosus.*
Bb. Grey mudstones, non-fossiliferous.
Ba. Black slaty shales, with *Leptograptus flaccidus*, *Dicellograptus Morrisi*, &c.
Ab. Black and grey shales, with *Didymograptus superstes*, *Thamnograptus typus*, &c.
Aa. Yellow and grey non-fossiliferous shales, with ribs and beds of hard siliceous flagstones.

These peculiar beds contain two bands of hard black shale, each about three feet in thickness. Some of the soft mudstone lines in them yield *Thamnograptus typus* (Hall), *Lasiograptus bimucronatus* (Nich.), *Dicranograptus ziczac* (Lapw.), &c. They therefore appertain to the same general group as our Glenkiln Shales of Dobb's Linn, the stratigraphical position of which is thus demonstrated to be below that of the Hartfell division.

These are the lowest beds exposed. They are broken by faults, and their interrelations complicated by some irregular contortions, so that it is difficult to arrive at any thing like a reliable estimate of their thickness. They give us, however, an excellent idea of the mineral characters of the Glenkiln group and of its great importance in the succession.

In all probability they are succeeded to the south by the overlying

Hartfell and Birkhill divisions; but no positive proof of this is obtainable, as the southern slope is gentle and overgrown with turf at this point.

(c) *Structure of the Glen.*

The evidence already collected is amply sufficient to enable us to determine the arrangement of the Moffat Series in this locality.

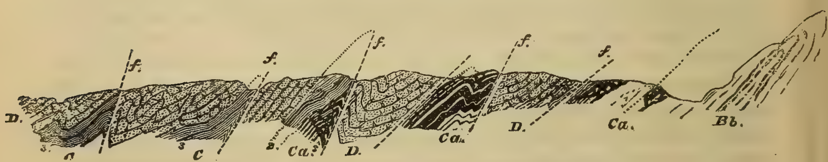
The strata are arranged in three parallel anticlinals. Of these the southerly one is by far the most important. Its axis runs in a straight line almost coincident with the bottom of the gorge. The level of this axis gradually declines to the west-south-west, so that newer and newer beds meet and cross over it as we proceed in that direction. The lowest beds exposed are the Glenkiln Shales, which occupy the bed and north bank of the stream, from the foot of the small burn entering from the north until they reach a point opposite the centre of the main cliff. Here they "nose in" upon the anticlinal, and the black beds of the Hartfell Series cross over one by one. They are followed in a similar manner by the "Barren Mudstone," through which the axis of the anticlinal runs to the foot of the cliff.

The second anticlinal exposes the Birkhill Shales in the hollow at the top of the cliff. The third exposes the *Rastrites-maximus* band in the greywackes beyond the summit.

Within the limits of the main cliff, as we have seen, the sequence is quite easy of comprehension; but in the streams to the north-east the contortion is so excessive that few beds are recognizable, and the various zones are inextricably intermingled.

Passing down the stream below the glen, however, an excellent section is visible (fig. 4), which enables us not only to completely confirm our former conclusions, but gives us a good idea of the dislocated character of the rocks of the neighbourhood.

Fig. 4.—*Section in Selcoth Burn.*



D. Purple and grey flagstones and graywackes.
C. Grey and purple shales with grey and black seams.
3. Zone of *Rastrites maximus*. 2. Zone of *Monograptus spinigerus*.
Ca. Black flags and shales with *Monograptus gregarius*, *Diplograptus vesiculosus*.
Bb. Pale mudstones, non-fossiliferous.
fff. Faults.

Along this line the Moffat Series emerges from below the greywackes in six distinct anticlinals. The axis of each of these arches is inverted, the degree of inversion gradually decreasing as we descend the course of the stream. With one doubtful exception each of these anticlinals is a faulted one, a portion of the inverted leg of each being lost.

It is interesting to note how the degree and intensity of this inversion decreases in proportion as we pass outwards from the chief anticlinal line; and, as we shall see in the sequel, the section is an admirable illustration of the general structure of the whole of the Moffat district.

The beds exposed and their interrelations can be understood from the figure (fig. 4). The fourth anticlinal is the only one which calls for description in this place. Its strata, in addition to yielding all the fossils of the Lower Birkhill Shales, include also an almost unbroken mass of the Upper Birkhill beds. Their fossils are beautifully preserved, and embrace *Rastrites maximus*, *Monograptus turriculatus*, *M. Halli*, and other forms peculiar to the very highest band of the Birkhill Shales.

Conclusion.

It is evident from the preceding description that our conclusions regarding the sequence and fossils of the Moffat Shales, deduced from our study of the rocks of Dobb's Linn, are perfectly sound. The succession in the present locality is easily interpreted by their aid, and the inferiority of the shales and mudstones to the great greywacke group in which they are imbedded is amply demonstrated. We have here gained a much fuller insight into the thickness and lithological characters of the Glenkiln Shales, which are seen to have an importance which would never have been suspected from the insignificant exposure of these beds at Dobb's Linn, and we are now in a position to commence the study of the numerous black-shale bands of the district.

§ II. *Description of the Bands of Black Shale to the South of the Moffat-Yarrow Valley.*

(a) *Black Bands to the South-west of St. Mary's Loch.* (Plate XI., Map No. II.)

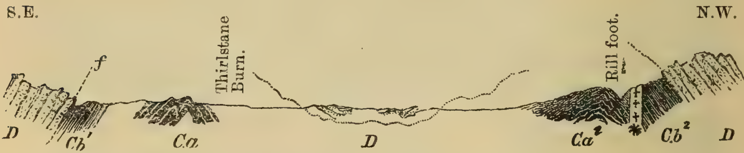
Nowhere in the Moffat district are the bands of black shale so continuous, their strata so little dislocated or confused, or their fossils so well preserved as in the high ground which lies to the south-west of St. Mary's Loch, and forms the watershed between the upper portion of the river-basins of the Ettrick and Yarrow. Four distinct black bands are here apparent, about half a mile apart, running approximately parallel with each other and with the main longitudinal valley to the north. Numerous streamlets descend the opposite slopes of the watershed, generally at right angles to the black-shale bands, but occasionally flowing over them for some distance. These furnish us in many instances with several exposures of the component strata of each band at different points along its course. In this way we obtain a large amount of confirmatory and supplementary evidence, which no one who is acquainted with the wrinkled and dislocated character of the Moffat rocks in any single exposure can fail to appreciate at its full value.

i. *First or Muckra Band.*

The most northerly of the black bands of this subregion runs parallel with the course of the upper Yarrow, from the immediate neighbourhood of St. Mary's Loch, crossing the watershed about midway along its course, and finally disappearing above the farm of Bodsbeck, opposite the central point of the Moffat valley.

Crosscleuch (fig. 5).—Half a mile to the south-west of St. Mary's Loch this band crosses the small stream known as Whitehope Burn, a short distance above the farmhouse of Crosscleuch. Here a little rill enters the burn from the east. At its mouth occurs an exposure of grey shales with black bands, traversed by a dyke of greenstone, but dipping steadily to the northward below the greywackes of the neighbourhood at an angle of about 45°. The presence of numerous white-clay bands in the grey and black beds enables us at once to identify them provisionally with the highest bands of the Birkhill Shales. This identification is fully verified by an examination of their included fossils, which embrace, among others, *Rastrites maximus* (Carr.) and *Monograptus Halli* (Barr.), forms strictly peculiar to the highest zone of the Birkhill Shales of Dobb's Linn.

Fig. 5.—*Section above Crosscleuch.*



D. Flagstones and greywackes of the country.
Cb'. Grey and purple shales faulted and shattered. *Monograptus Hisingeri*,&c.
*Cb*². Grey shales, with seams of black and white mudstones, well bedded, containing *Rastrites maximus*, *R. hybridus*, *Monograptus spinigerus*, *M. Halli*, &c.
Ca. Black carbonaceous flags and shales, with *Diplograptus vesiculosus*, &c.
* Dyke of greenstone.
f. Fault.

Immediately to the south these shaly strata are underlain by convoluted black shales with *M. spinigerus* (Nich.), beyond which they are repeated and form the right bank of the stream for several yards. Passing over a few fragmentary patches of greywacke in the bed of the burn, indicative of the presence of a small synclinal, the Moffat Series again rise to the surface. At the foot of Thirlstane Burn, a few yards beyond, we come suddenly upon a boss of hard flaggy black shales, which both in appearance and stratigraphical position agree precisely with those at the summit of the *D.-vesiculosus* band of the Linn. They yield also its characteristic fossils, *D. vesiculosus* (Nich.) and *C. innotatus* (Nich.). They are succeeded to the south by isolated fragments of black rock showing the peculiar variegated lines of the *M.-gregarius* zone, and affording *M. tenuis*, *C. scalaris*, and others of its commoner fossils, and the section is closed by a group of black, grey, and purple beds, faulted against the greywackes of the country to the south. These faulted beds yield *Monograptus spinigerus* (Nich.) and *M. Hisingeri* (Carr.), and are clearly a portion of the Upper Birkhill group.

Riskinhope Burnfoot.—Following the general direction of the band along its line of strike to the south-west, it is seen to cross the mound-like ridge of Peat Hill at a very oblique angle, and its strata are again visible near the mouth of Riskinhope Burn. Here the shales are too contorted and broken to enable us to make out the sequence; but the mineralogical characters and fossils of the central and more convoluted beds are recognizable as those of a portion of the Lower Birkhill group. The terminal strata are less shattered. They yield a few exquisitely preserved Upper Birkhill forms, and pass distinctly below the greywackes to the north at a high angle.

For the succeeding mile and a half, the position of the band is indicated by a peculiar road-like indentation in the smooth grass-grown flank of Muckra Hill. It arrests the drainage of the hill-slope and gives rise to a row of perennial springs.

Fig. 6.—*Section in Muckra Burn.*

D. Flagstones and greywackes of the Gala group. *Cb.* Contorted grey shales.
Cb[3]. Grey shales with black and white seams, containing *Rastrites maximus*, *Monograptus Halli*, &c.
Cb[2]. Grey shales with black bands and seams of white clay, with *Monograptus spinigerus*, *M. Clingani*, *M. Hisingeri*, trails of Annelids, nodular concretions, &c.
2. Horizon of *Monograptus spinigerus*. 3. Horizon of *Rastrites maximus*.
Ca. Black flagstones and shales, greatly shattered, non-fossiliferous.
Bb. Pale flaggy mudstones and shales.
f. Fault.

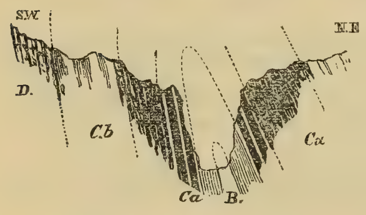
Muckra Burn (fig. 6).—The second important exposure of the rocks of this band is met with in the Muckra Burn, which is crossed obliquely by the dark shales at a point about midway along its length. As in the former instances the beds in the southern (or inverted) portion of the exposure are so shattered and altered that their detailed identification is well-nigh impossible. There is, however, enough visible to enable us to assure ourselves of the fact that they are actually arranged in an anticlinal form. The central beds resemble the "Barren Mudstones" of the Hartfell Shales. They are followed on both sides by black beds which come into the place of the Lower Birkhill Shales. These are succeeded, in their turn, by the grey and black beds of the Upper Birkhill, which to the south are visibly in conformable contact with the greywackes.

The structure of the northern half of the exposure, however, is perfectly clear. Its beds are those of the grey division of the Birkhill Shales, much convoluted and fractured, but very slightly altered.

They form two subsidiary and partly broken anticlinals, and the highest beds pass visibly beneath the greywackes to the north. Strata belonging to the *D.-cometa*, *M.-spinigerus*, and *R.-maximus* zones are exposed here and there, and fossils are abundant and well preserved. The white lines of the highest division are very conspicuous, as are also the inferior bands of grey sandy mudstone and shivery shale, with their characteristic Annelide-trails and concretions. The commonest fossils are *Rastrites maximus* (Carr.), *R. capillaris* (Carr.), *Diplograpsus palmeus* (Barr.), *Monograptus Halli* (Barr.).

Black Grain.—Proceeding to the south-westward, the band next crosses the watershed into the basin of the Ettrick, where its rocks are first visible in a small score near the head of Black Grain. Here, although the beds are highly metamorphosed and wholly unfossiliferous, their steady dip and the distinctness of the mineral characters of the various zones, enable us to recognize the chief subdivisions at a glance. The Barren Mudstones of the Hartfell series occupy the centre of the exposure. To the south they are covered by the black flags and shales of the Lower Birkhill; and the exposure is closed by the more recent grey and black shales with white-clay bands, which dip steadily under the greywackes to the south at an angle of about forty degrees.

Fig. 7.—*Generalized Section across Fala Grain.*



D. Greywackes and flagstones.
Cb. Grey flaggy shales with black and white seams.
Ca. Hard black flags and shales, with seams of variegated mudstone. *Diplograptus vesiculosus*, *Monograptus gregarius*.
B. Pale non-fossiliferous mudstones.

Fala Grain (fig. 7).—This reading of the sequence is confirmed by the beautiful section visible in Fala Grain, a small burn descending the southern slope of Herman Law. In the lower portion of its course the bed of this stream coincides with the general direction of the black-shale band under description, and the Moffat strata are admirably exposed in the steep cliffs on its banks. The first beds visible to the north-east are grey and black shales with a northerly dip. These are underlain by the main mass of the zones of *M. gregarius* and *D. vesiculosus*, whose variegated and hard flag-like strata form the walls of the gorge for a distance of nearly 200 yards. A great thickness of barren grey mudstone succeeds, and probably forms the lowest stratum exposed. To the south the dark shales and flags reappear, and, as before, in an almost vertical attitude. Near the foot of the stream the section is completed by the grey and black shale group with the usual white-clay bands, in conformable contact with the greywackes to the south, conspicuously displayed in the hill-face to the left.

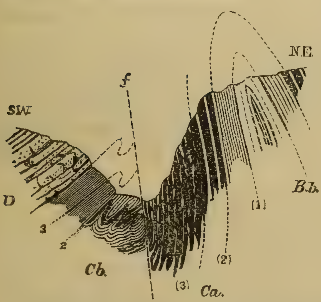
The distinctive fossils of the Lower Birkhill Shales may all be collected at this locality. The upper subdivision is too much broken and altered to yield more than a few rare specimens.

It is needless to follow this band in its prolongation to the south-west. The exposures already examined amply demonstrate that in this district there are no beds in the rocks of the band that are not visible in our typical section of Dobb's Linn. Wherever the succession from the shales into the greywackes is unbroken, the latter are immediately underlain by the representatives of our highest Birkhill bands, below which occur in their natural order the subjacent strata of our typical locality.

Thirlstane Burn. (Plate XIII. Plan B.)

Midway between the first and second of the black-shale bands, an excellent local exhibition of a portion of the Moffat series occurs at the head of a small stream falling into Thirlstane Burn (fig. 8).

Fig. 8.—*Section at Thirlstane Score.*



D. Purple flagstones and flaggy shales.
Cb. Grey shales with seams of black, yellow, and white mudstones.
3. Horizon of *Rastrites maximus*, *Monograptus Halli*, &c.
2. Horizon of *Monograptus spinigerus* (= *Sedgwicki*).
Ca. Black flags with partings of variegated mudstones, &c.
(3) Zone of *Monograptus gregarius*. (2) Zone of *Diplograptus vesiculosus*. (1) Zone of *D. acuminatus*.
Bb. Pale and non-fossiliferous mudstones.
f. Fault.

The shales are first visible about midway along the course of the last-named stream, but the section at that spot is valueless for purposes of comparison. At the head of the tributary burn the whole sequence of what are instantaneously recognized as the Birkhill Shales is visible, from the green mudstone of the *D.-anceps* band into the greywackes.

A fault traverses the beds obliquely from south to north, and this is crossed at a very acute angle by a subordinate anticlinal line, a little below the greywackes. To the west of this anticlinal the beds are in their natural position; to the east they are slightly inverted.

The *D.-vesiculosus* band forms, as usual, a steep cliff and yields its peculiar fossils in abundance. The *M.-gregarius* zone with its variegated and nodular seams is seen in the sides and base of the cliff, the coloured lines being especially conspicuous in some small bosses on the floor of the score. The grey and black beds of the Upper Birkhill group form both sides of the little anticlinal already referred to, and their lower beds are much broken up along its course. The *M.-spinigerus* zone, however, is easily identified, exhibiting the peculiar aluminiferous black shales, with their excess of pyrites, their slightly concretionary structure, and their beautifully preserved examples of *Monograptus spinigerus* (Nich.). The highest or *R.-maximus* zone of the Upper-Birkhill Shales is here even more satisfactorily exposed than at Dobb's Linn. Many of the mudstones are of a deep purple colour, but all show the characteristic white and yellow lines and thin seams of dark shales, loaded with Graptolites in a state of high relief.

These beds pass under the greywackes at a low angle near the head of the score, where the overlying beds are seen to be much thinner and more flag-like than at Dobb's Linn.

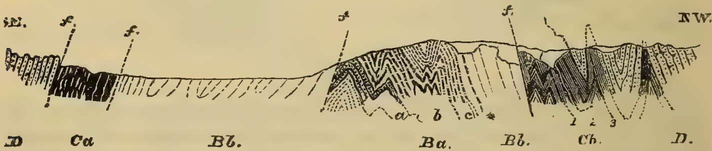
The opposite leg of the chief anticlinal is hidden below the turf: some hardened black shales projecting from the hill-side below possibly belong to it.

Every fossil of the Birkhill series of our typical section may be collected in the corresponding zones of this locality. Those detected and noted by myself will be found in the lists given in the second part of this Memoir.

ii. *Second or Riskinhope Band.*

Moory Syke.—The finest section of the deposits included in the second band of the black shales is met with near the eastern extremity of the band. It occurs in the course of the small stream known locally as the Moory Syke, at a point about half a mile to the south of the Thirlstane score (fig. 9).

Fig. 9.—*Section at the head of Moory Syke.*



D. Greywackes and flagstones, grey and purple, with partings of flaggy shale.
Cb. Grey, purple, and yellow shales, with seams of black mudstones and white-clay lines, containing *Rastrites maximus, Monograptus Halli, Diplograptus folium*, &c.
1. Seam of *Monograptus Clingani.* 2. Horizon of *Monograptus spinigerus.* 3. Horizon of *Rastrites maximus.*
Ca. Black carbonaceous flags and shales, with partings of variegated clays, containing *Diplograptus vesiculosus, Monograptus gregarius*, &c.
Bb. Pale grey and green non-fossiliferous mudstones.
* Fossiliferous seam in ditto.
Ba. Black slaty flags and shales, with seams of white mudstones in *c.*
a. Zone of *Pleurograptus.* *b.* Zone of *Dicranograptus Clingani.* *c.* Zone of *Climacograptus Wilsoni.*
fff. Faults.

To the north of the chief exposure at this locality two preliminary anticlinals display a few feet of the grey-shale group, exhibiting the peculiar white-clay seams, and affording some characteristic fossils. In the main section the grits of the district are seen to repose, at an angle of about 60°, upon the grey and white-lined shales of the *R.-maximus* zone. The component beds of this zone are by no means so satisfactorily exhibited as in Thirlstane Syke; but the characteristic fossils are abundant. Its strata lie in their natural order upon an excellent section of the dark and pale shales of the zone of *M. spinigerus*. Here we recognize immediately the peculiar black pyritous mudstones, with their beautifully preserved examples of *M. spinigerus*, *M. Hisingeri*, &c., and the accompanying grey and yellow sandy shales with their strange reticulations, so strikingly characteristic of the zone at Dobb's Linn.

Below the *M.-spinigerus* seams the shales are much contorted; but, running as a continuous bed among them, zigzag fashion, we notice with much interest the extraordinary "*Clingani*" band of our typical section. It is here nearly a foot in thickness, and is crowded with well-preserved examples of *Monograptus Clingani* (Carr.) and *M. leptotheca* (Lapw.). These Upper Birkhill beds are faulted immediately against the "Barren-Mudstone" zone of the Upper Hartfell Shales, the whole of the Lower Birkhill beds being missing from this spot. The "Barren Mudstone" reposes in its natural order upon a distorted mass of the slaty black shales of the Lower Hartfell group. The highest or *Pleurograptus* zone of the latter is remarkably conspicuous, being repeated again and again in the section. It yields a few of the characteristic fossils, and shows many of the soft white sandy mudstones, which are here much thicker than at Dobb's Linn.

The inferior *D.-Clingani* and *C.-Wilsoni* zones occur in the abrupt arches below. Their beds are almost destitute of fossils; the chief forms obtainable are *Dicranograptus ramosus* (Hall), *Dicellograptus Forchhammeri* (Gein.), *Diplograptus foliaceus* (Murch.), *Corynoides calycularis* (Nich.), &c., an association sufficient to place beyond doubt our determination of their place in the succession.

They are faulted at their southern termination against a long convoluted sheet of the "Barren Mudstone," which is very indifferently shown in the bed of the stream. This is followed by a portion of the *D.-vesiculosus* band of the Lower Birkhill group, dipping to the south and overlain by a fragment of the variegated *M.-gregarius* zone with *Monograptus gregarius*, *M. lobiferus*, &c. The latter is finally faulted abruptly against the neighbouring greywackes.

Earl's Hill.—From the Moory Syke the black-shale band passes to the south-westward over the crest of Earl's Hill. In the deep notch in the ridge a good exposure of its beds may be examined. The faulting and contortion so conspicuous in the preceding section are here continued and greatly intensified. The central beds of the *M.-gregarius* zone are visible to the right, marked by the presence of *M. lobiferus* (M'Coy) and *M. tenuis* (Portl.). They are faulted against the white-banded zone of *Pleurograptus linearis*, which in the floor of the score yields good examples of its most characteristic fossil forms, *Pleurograptus linearis* (Carr.), *Amphigraptus divergens*

(Hall), *Leptograptus flaccidus* (Hall), *Diplograptus quadrimucronatus.* To the left the strata are excessively metamorphosed and are of a deep purple colour; those to the extreme south-west appear to belong to the Glenkiln group.

Riskinhope Burn (fig. 10).—Passing over the very indifferent exposure of the strata of this band in the glen of the Whitehope Burn, we cross the succeeding ridge into the higher portion of the hollow valley of the Riskinhope. This little stream runs generally along the strike of the dark shales, and affords many small sections in its banks. In the lowest of these sections we have a full exhibition of the zones of *D. vesiculosus* and *M. gregarius*, the flag-like strata forming the bounding walls of the stream-bed for some distance, and clearly arranged in a distinct anticline.

Higher up the stream an ascending section may be traced through all the succeeding Birkhill zones into the grey flags of the *R.-maximus* band, the strata dipping to the south in their natural order. Some little distance beyond, a similar succession can be made out on the north leg of the anticlinal. The miniature cliffs which next form the south bank of the stream expose a continuous section of the contorted bands of the Birkhill Shale. Especially conspicuous are the peculiar greenish-yellow beds of the zone of *M. spinigerus*, with their Annelid-trails and characteristic superficial reticulations. Beyond them the white-lined flaggy shales of the *R.-maximus* band abound, and are seen to be in irregular contact with the greywackes, which here form a portion of the southern bank. At the head of the gully the grey and black beds again emerge and yield well-preserved fossils of the *R.-maximus* band. All the strata described clearly form portions of a single anticlinal, the axis of which crosses the stream at a very oblique angle, about 200 yards above the point where the dark shales are first apparent.

To the south the greywackes last mentioned are faulted against the following succession:—

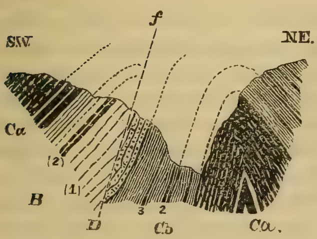
Greenish-grey shivery mudstones (S. at 60°)	5 feet.
Dyke of zeolitic trap	8 feet.
Thick-bedded black flags and shales with *D. vesiculosus, M. gregarius*, &c.	20 feet.

This can only be interpreted as the southern side of a second anticlinal, faulted along the summit of the arch, the dyke of trap coming into the place of the *D.-anceps* band of the Upper Hartfell Shales.

A hundred yards beyond the section last noted, and in the line of strike of its component beds, we meet with the missing *D.-anceps* zone in a small score in the hill-side to the south. It is imbedded in a convoluted mass of slightly altered "Barren Mudstone." The peculiar soft black seams of the zone are easily identified and yield (as usual in a state of partial relief) its conspicuous species *Dicellograptus anceps* (Nich.), *Diplograptus truncatus* (Lapw.). The general arrangement of the dark shales in the glen will be understood on an examination of the following section (fig. 10), in which all the foregoing facts are generalized.

In the prolongation of the strike to the south-west we reach a second score, which affords a section completely verifying our view

Fig. 10.—*Riskinhope Burn.* (Generalized Section.)



D. Flagstones and greywackes, contorted.
Cb. Grey shales with black and white seams.
3. Horizon of *Rastrites maximus.*
2. Pyritous shales with *Monograptus spinigerus* &c.
Ca. Black flaggy shales visible in large anticlinal in lower portion of the gorge.
B. (1) Grey and green mudstones.
(2) Soft black shales with *Dicellograptus anceps*, seen in scores above the head of the burn.
f. Fault.

of the attitude and sequence of the beds. The strata exposed all dip steadily to the southward at about 60°, in the following (descending) order:—

(*c*) Steep cliff formed of the hard flags and shales of the *D.-vesiculosus* and lower *M.-gregarius* bands, yielding *D. vesiculosus, M. gregarius, M. attenuatus,* &c.	30 feet.
(*b*) Soft grey and green mudstones with black bands (clearly the zone of *Dicellograptus anceps,* &c.)	20 feet.
(*a*) Soft shivery barren mudstones, grey and green	20 feet.

Above the section the scattered fragments of shale lying on the hill-slope prove the presence of the grey and white-lined Upper Birkhill Shales at this point. The summit of the ridge is formed by the greywackes of the country.

The Yellow Mire.—Following the line of depression marking the place of the Black Band over the little watershed, we reach a broad peat-clad hollow, drained by several small feeders of the Muckra Burn. This hollow owes its origin to the extraordinary expansion of the band of easily eroded black shales at this locality, where its maximum diameter probably exceeds a quarter of a mile. The yellow and iron-stained fragments of the "Barren Mudstones" and the overlying shales are exposed here and there along the courses of all the little rills that wander through the moss, giving to the spot its quaint but characteristic title of the Yellow Mire.

Along the northern margin of the band lie the Birkhill Shales. The upper and greyer division of the group is alone exposed. Its strata are much contorted, but are comparatively unaltered. They contain in abundance the characteristic fossils of the *R.-maximus* zone, which are found in good preservation in the grey shales immediately in contact with the greywackes at the point where the eastern arm of the Muckra Burn emerges from the moss.

None of the forms proper to the Lower Birkhill Shales are obtainable, the inferior portion of the Birkhill group being apparently represented, in part, by a thin and excessively crumpled band of dark flagstones interposed between the Grey Shales and the Barren Mudstone. It lies approximately along the general course of the main line of fault that runs along the strike from the Wisp to Brockhope Burn, and which for several miles has placed a narrow seam of greywacke in the geographical centre of the band, dividing it into two parallel lines of black shales.

In some shallow scores in the middle of the Yellow Mire there are some indifferent exposures of the central, and therefore oldest, beds of the band. The deepest bed visible is the *Pleurograptus-linearis* zone of the Upper Hartfell Shales. The black thin-bedded shales of the zone with their white lines admit of immediate identification. Fossils are rare; *P. linearis* (Carr.) and *Leptograptus flaccidus* (Hall) are both present. The white band at the summit of the zone is very conspicuous, as are also the shivery mudstones of the Barren beds.

Of the southern leg of the anticlinal at this locality we know very little; a few Birkhill forms may, however, be collected from the scattered fragments of shale to the south of the scores. The strata themselves are all hidden from sight by turf and moss.

iii. *Third or Whitehope Band.*

Whitehope Burn (fig. 11).—This band attains its greatest diameter near the small cottage of Whitehope, to the west of Earl's Hill, where a tolerably continuous transverse section is visible in the course of the

Fig. 11.—*Section below Whitehope Cottage.*

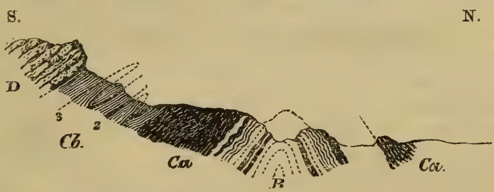
D. Flagstones and grits.
Cb. Grey shales with black bands, yielding *Monograptus Halli* in relief.
Ca. Black pyritous flags with seams of variegated mudstones. *Monograptus gregarius*, *Rastrites peregrinus*, &c.
f. Fault.

stream below the cottage. Near the northern edge of the band a thin group of grey shales with black seams, yielding *Monograptus Halli* (Barr.) and *Rastrites maximus* (Carr.), subsides below the greywackes to the northward at a gentle angle. The presence of these beds at this point is due to a small arch of the strata, above which the greywackes pass unbroken in the steep hill-face to the left, descending again to the level of the bed of the stream to the south. The most northerly strata of the main anticlinal which are actually visible occur at the angle of the stream some distance beyond, where there is a boss of crumpled Lower Birkhill flaggy and carbonaceous shales containing fragmentary examples of *Monograptus lobiferus* (M'Coy) and *M. gregarius*. Similar beds, greatly disturbed, but clearly associated with grey shales, succeed, and are irregularly exposed as far as the foot of Easter Burn, much of the section being buried under clay and boulders. The remainder of the traverse is formed of the various zones of the Birkhill Shales, from the *D.-vesiculosus* band to that of *M. spinigerus*. They are capitally shown in the banks of Easter Burn, and afford an abundance of Graptolites, especially of those of the zone of *M. gregarius*, the peculiar variegated strata of which are very conspicuous in several small quarries on the left of the stream. The deepest beds exhibited are greatly disturbed; but the strata gradually assume their natural position towards the southern margin of the band, where a few of the highest grey-shale beds are cut out by a small fault at their point of contact with the greywackes.

This single section might perhaps be regarded as affording sufficient proof of the identity of the strata of this band with the Moffat beds already described, and of their corresponding inferiority to the greywackes. The evidence is defective, however, in demonstrating the presence of any thing older than the Birkhill Shales, and in defining the relation of the latter to the greywackes to the south.

Black Grain (Plate XIII. Plan C; fig. 12).—These missing links in the chain of evidence are both supplied by a remarkable section of the rocks of the band in Black Grain, a small stream descending the opposite slope of the watershed, about two and a half miles to the south-west of Whitehope. Between the two localities the band can be traced almost continuously by the usual N.E. and S.W. depression due to its presence, as well as by the occasional exposure of the characteristic shales and mudstones along its course.

Fig. 12.—*Black Grain*. (Sketch Section.)



D. Cliff of purple flagstones.
Cb. Grey and purple shale, with black and white seams.
3. Zone of *Rastrites maximus*. 2. Zone of *Monograptus spinigerus*.
Ca. Hard black flags and shales.
B. Contorted pale mudstones with black seams.

In Black Grain the greywackes of the country dip outwards from the margins of the band, both to the north and south. To the north the succession is unintelligible. To the south the greywackes form the summit of a steep cliff, which here causes an abrupt deflexion of the stream-course. They visibly overlie a great thickness of grey and purple shales, containing black seams and thin lines of white and yellow clay.

These are clearly the Upper Birkhill Shales. They yield in abundance the characteristic fossils *Rastrites maximus* (Carr.) and *Mono-*

graptus Halli (Barr.), but are at first sight apparently much thicker than usual, the result of several small inverted folds.

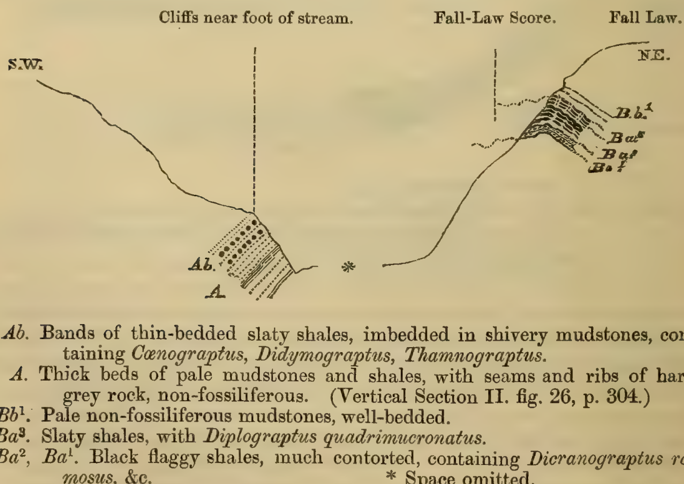
In the lower portion of this grey group we find a tolerably complete exhibition of the *Monograptus-spinigerus* or *Sedgwicki* zone. Some of its most prolific beds at this locality occur on the north bank of the stream, opposite the base of the cliff.

In the main section they are brought down by a small fault against the zone of *Monograptus gregarius*, prominent by its peculiar variegated clays. This reposes upon the hard black flags of the zone of *Diplograptus vesiculosus*, which stand up almost on edge in gnarled rugged bosses on both sides of the stream. In the sloping bank on the left of the stream several deep scores expose sections of the underlying black and green shivery mudstones of the *Dicellograptus-anceps* zone of the Upper Hartfell Shales. They are charged with *Dicellograptus anceps*, *Diplograptus truncatus*, &c., and are arranged in several converging folds, piercing the *D.-vesiculosus* flags like a gigantic wedge.

iv. *Fourth or Berrybush Band.*

Berrybush Burn (fig. 13).—The fourth and most southerly band of black shale in this district attains its easternmost extension in the deep valley drained by the small burn of Berrybush. Midway along the course of the burn the steep flank of the mountain of Fall Law, which bounds the valley to the northward, is gashed by a deep score dug out of the tractable shales and mudstones of the Moffat Series, whose convoluted beds cross it almost at right angles to its general direction.

Fig. 13.—*Berrybush Burn.* (Sketch Section.)



Ab. Bands of thin-bedded slaty shales, imbedded in shivery mudstones, containing *Cœnograptus*, *Didymograptus*, *Thamnograptus*.
A. Thick beds of pale mudstones and shales, with seams and ribs of hard grey rock, non-fossiliferous. (Vertical Section II. fig. 26, p. 304.)
Bb^1. Pale non-fossiliferous mudstones, well-bedded.
Ba^3. Slaty shales, with *Diplograptus quadrimucronatus*.
Ba^2, *Ba*^{1}. Black flaggy shales, much contorted, containing *Dicranograptus ramosus*, &c. * Space omitted.

At the summit of the score the "Barren mudstones" of the Upper

Hartfell Shales plunge into the grass-grown hill-face at a steep angle. They visibly repose upon the thin-bedded shales and white mudstones of the *Pleurograptus* zone, which affords abundant, but miserably preserved examples of such characteristic fossils as *Leptograptus flaccidus* (Hall) and *Diplograptus quadrimucronatus*. Below, the walls of the score are formed of the thicker-bedded black flags of the zone of *Dicranograptus Clingani*, which undulate in numerous irregular folds, and yield a few fragmentary specimens of their peculiar species *D. Clingani* and *Climacograptus caudatus*. The deepest beds visible are the black, flaggy, and flake-like beds of the zone of *Climacograptus Wilsoni*, in which the only fossils apparent are the characteristic *Discina* and fragments of sponges. The remainder of the descent into the bottom of the glen is obscured by the débris washed out of the score.

That the strata thus hidden from observation are those of the naturally subjacent Glenkiln Shales is at once made evident if we descend the main stream for a short distance. About 200 yards below the foot of the score we encounter a grand group of sections of the beds of that division, all dipping steadily to the southward, at an angle of about 60°, into the face of the steep ridge on the right of the burn.

No one who has examined the Glenkiln beds of the symmetrical section of Craigmichan Scaurs, where their inferiority to the Hartfell and Birkhill divisions is so unmistakably exhibited, can hesitate to identify with them all the strata exposed in these sections. We have the same peculiar yellowish-grey and white mudstones, here concretionary or shivery and iron-stained, there flaggy and riddled by innumerable burrows of Annelides; the same thick-bedded grey seams of siliceous rock, weathering like ribs of flint; and the same hard but easily disintegrating bands of black shale, conspicuous in the light-coloured mass in which they are intercalated. They are here, however, much less altered than at Craigmichan; there is no direct proof of their repetition by fold or fracture, and at the same time they are all in such a position as to admit of complete study.

The largest sections occur near the foot of the burn. In the second of these the succession is exhibited which is tabulated on fig. 26, p. 304.

This is one of the most satisfactory sections of the beds of the ribbed-shales group of the Glenkiln division exposed within the limits of the Moffat district. Its strata lie at gentle angles, are quite unaltered, and admit of thorough examination *in situ*.

The fossils of the included black-shale bands embrace a large majority of peculiar Glenkiln forms, chiefly *Didymograptus superstes* (Lapw.), *D. serratulus* (Hall), *Cœnograptus gracilis* (Hall), *C. surcularis* (Hall), *C. explanatus* (Lapw.), *Dicranograptus ziczac* (Lapw.), *Dicellograptus sextans* (Hall), *Diplograptus bimucronatus* (Nich.).

These beds occupy the centre of the band, which at this place is inferred to be about 200 yards in diameter. To the north, as we have seen, they are surmounted by a complete development of the

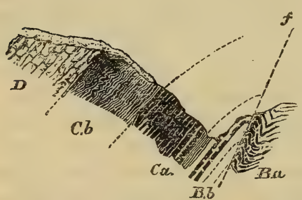
Lower Hartfell Shales. To the south the ground is covered with vegetation, and none of the Moffat shales are visible.

Cowans Croft, &c.—Following the band to the south-west above the head of the valley, we observe that its great lateral extension gives rise to a wide peat-covered flat, like that of the Yellow Mire. It is crossed near its eastern extremity by the "Captain's Road," an almost obliterated mountain-track between Crosscleuch and the valley of the Ettrick. In this track, and the little quarries and scaurs in its neighbourhood, fragments and even bedded patches of the Hartfell and Birkhill shales are discernible on both sides of the central portion of the band.

Additional evidence of the presence of the Birkhill Shales may be gathered at intervals along the sloping hollow followed by the band to the south of the summit of Ramsey Knowe. In this direction the band rapidly contracts its diameter to one fourth of that which it possessed at the head of Berrybush.

Scabcleuch (Plate XIII. Plan D).—Crossing the watershed into the hollow drained by the stream of Scabcleuch, a small tributary of the latter descends the western side of Ramsey Knowe exactly in the line of the black-shale band. This has worn a little gorge, known as "The Slunk," out of the mossy slope, and has laid bare an admirable exposure of the junction of the beds of the black band and

Fig. 14.—*Section across the Slunk, Scabcleuch Burn.*



D. Greywackes much contorted, seen at stream foot.
Cb. Grey shales with black and white bands, contorted, non-fossiliferous.
Ca. Well-bedded black flags and shales with partings of variegated mudstones. *Monograptus gregarius, D. vesiculosus*, &c.
Bb. Pale mudstone with seam of black shale.
Ba. Shattered black slaty shales with *Pleurograptus.*
f. Fault.

the greywackes to the south (fig. 14). Hitherto, beyond the detection of a few fragments of the higher Moffat Shales near the southern margin of the band, we have obtained no positive proof of the presence of the Hartfell and Birkhill shales to the south of its longitudinal axis. In this exposure that proof is complete and decisive. The deepest beds seen to the north, towards the centre of the band, form a portion of the *Pleurograptus* zone of the Lower Hartfell Shales, yielding *Leptograptus flaccidus* (Hall), &c. They are in irregular contact with a broken mass of the "Barren Mudstone," beyond which certain black, yellow, and grey bands, that represent the *D.-anceps* zone, plunge visibly beneath the shivery mudstone with *Diplograptus acuminatus*, which forms the base of the Birkhill Shales. Upon this reposes 9 feet of hard thick flags (clearly the *D.-vesiculosus* zone), yielding the characteristic fossils *Diplograptus vesiculosus* (Nich.), *Monograptus tenuis* (Portl.), &c. This subsides below a thick mass of thinner flags, with bands of variegated mudstones, red, yellow, and blue, affording in its lower portion *Monograptus gregarius* (Lapw.), *M. cyphus*, (Lapw.), &c., and in its higher beds *Rastrites peregrinus* (Barr.), *Monograptus communis*, &c.

The foregoing strata dip to the south at 45°–60°, and near the foot of the stream the succession is closed by a group of grey and black shales with white lines, clearly the Upper Birkhill beds, which pass beneath the greywackes of the district to the south.

Shiel Syke.—A small and indifferent section on the opposite side of the hollow to the south-west affords evidence of a further contraction of the band. It exhibits merely a few feet of the *D.-vesiculosus* zone and a portion of the highest Grey-Shale group, dipping to the north—enough, however, to prove the presence of the Birkhill shales to the north of the axis of the band.

Cossar-Hill Burn.—In Cossar-Hill Burn a few shattered and highly indurated black beds are all that remain to represent the Berrybush band, and in the next valley it seems altogether to disappear below the contorted greywackes.

Summary.

At this stage, therefore, our study of the strata exposed in the four uninterrupted black-shale bands to the south-west of St. Mary's Loch has established the following propositions:—

(i.) The sequence, lithological characters, and peculiar fossils of the subgroups of strata included within these bands are identical in every respect with those of the various zones of the Moffat series as exposed in our typical section at Dobb's Linn.

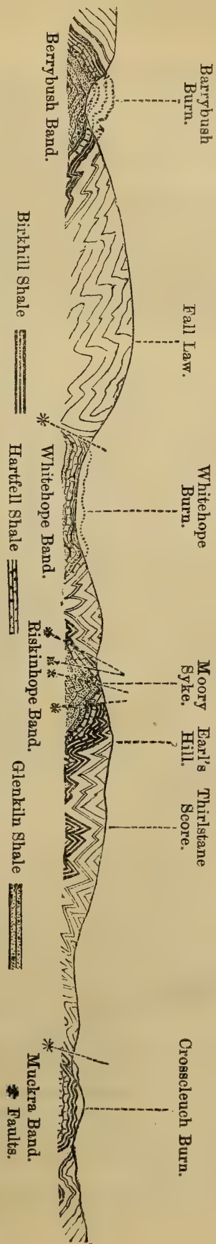


Fig. 15.—*General Section through the district to the south-west of St. Mary's Loch.*
(Scale 4 inches to 1 mile.)

(ii.) The oldest and deepest beds of each black-shale band occur almost invariably in its central portions; and, where the succession is unbroken, those of the highest and most recent zone graduate upwards on both margins of the band into the basal beds of the surrounding greywackes.

These facts point unmistakably to the conclusion that the four parallel black-shale bands of this locality are formed by a repetition of one and the same great group of black shales, and that these owe their recurrence, not to the presence of a series of gigantic faults, but to several parallel folds of the strata. In other words, the rocks of the Moffat Series are the oldest deposits in this area, being inferior in stratigraphical position to the barren greywackes, through which they rise in anticlinal forms (see fig. 15).

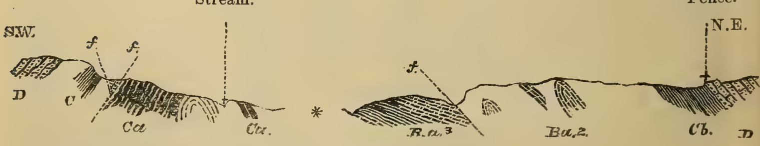
That these relationships hold good everywhere to the south of the Moffat valley will next be demonstrated.

(b) *Black Bands in the Valley of the Yarrow.*

To the north-east of the area last described there are several exposures of the shales and mudstones of the Moffat series. From their position, and from the attitude of the greywackes with which they are associated, there is a strong presumption that they rise to the surface in the prolongations of the anticlinals already noted. No direct evidence, however, is forthcoming upon this point, as the rock-sections are restricted to the miniature cliffs formed by a few of the small upland streams, and the intervening country is covered by turf, gravel, or peat. In the majority of the exposures the strata are too much shattered, or too imperfectly exhibited, to allow us either to give their original sequence or their present relations to the surrounding greywackes. There are, however, two exceptional sections at the extreme north-east of the area, in which the evidence upon the second of these points is distinct and unequivocal.

i. *Mount-Benger Burn* (fig. 16).—The finest exposure in this direction is afforded by the small stream which derives its title from

Fig. 16.—*Section in Mount-Benger Burn.*



D. Flaggy greywackes and thin grits and shales.
Cb. Purple and grey mudstones with seams of black shales and white clays, containing *Rastrites maximus, Monograptus Halli*, &c.
Ca. Contorted flaggy black shales with variegated partings. *Diplograptus palmeus, Monograptus triangulatus, M. gregarius*, &c.
*Ba*³. Well-bedded black slaty shales, highly fossiliferous, with *Pleurograptus linearis* &c.
*Ba*². Shattered black flaggy shales, with *Dicranograptus ramosus* &c.
* Space omitted. *f f.* Faults.

the farmhouse of Mount Benger, once the residence of Hogg, the Ettrick Shepherd. It occurs at the side of the high road between the town of Inverleithen and the valley of the Yarrow, about half a mile above the mouth of the burn.

Here the greywackes of the country are exposed in several large quarries in the hill-side, and with few local interruptions are seen to dip steadily to the north-west at high angles. Where a small fence crosses the burn, the highest beds of the dark-shale series emerge from below them in a similar attitude.

The first beds apparent are grey, green, and purple mudstones, in which are intercalated two groups of black-shale bands, with seams of white clay. They are much softer than usual, but otherwise present all the peculiarities of the *R.-maximus* zone of the Birkhill Shales. The fossils they contain are beautifully preserved; the characteristic forms *Rastrites maximus*, *Monograptus Halli*, and *Retiolites perlatus* are especially abundant.

Below the *R.-maximus* zone the talus obscures the section for several yards, and the next strata visible are hard, black, slaty flags of a couple of inches in thickness, barren of fossils except upon two or three horizons. They are clearly a portion of the zone of *Dicranograptus Clingani* of the Lower Hartfell Shales. In addition to *Dicranograptus ramosus* and *Dicellograptus Forchhammeri*, *Siphonotreta micula* (M'Coy) is perhaps their most abundant fossil.

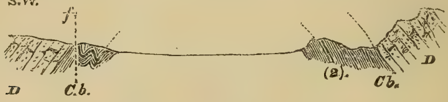
Beyond this point a badly exposed and greatly shattered section marks the position of faulted beds. Next succeeds a group of soft, slaty, black shales, containing in its higher portions several seams of white mudstone, and recognizable at a glance as the zone of *Pleurograptus linearis*. Its beds are almost flat, and are unbroken and unmetamorphosed. They swarm with the characteristic fossils of the zone, all of which are in excellent preservation. The most striking species obtainable are *Pleurograptus linearis* (Carr.), *Amphigraptus divergens* (Hall), *Dicellograptus elegans* (Carr.), *Diplograptus quadrimucronatus* (Hall).

For the next hundred yards the stream flows over alluvium and boulders, and the terminal beds of the section are met with at the foot of a small rill which enters from the north.

Here there is an exposure of the greater number of the zones constituting the Birkhill-shale group. The deepest beds visible are those of the upper portion of the *D.-vesiculosus* band, hard and flag-like, and yielding *Diplograptus vesiculosus* (Nich.), *Monograptus tenuis* (Portlock), &c. These are followed by the variegated beds of the *M.-gregarius* zone, which, much faulted, and succeeded irregularly above by the grey group of the Upper Birkhill Shales, with *Monograptus spinigerus*, *M. tenuis*, &c., occupy the remainder of the exposure, and pass below the greywackes to the south at an angle of about 60°.

ii. *Eldinhope Burn* (fig. 17).—On the opposite side of the Yarrow a small section is visible in the burn of Eldinhope, about 200 yards above the small cottage. On both sides of the exposure the greywackes dip from off the Moffat beds at an angle of about 45°. Of the Moffat beds themselves only the highest beds are visible. To the south a group of grey shales, folded and broken, crops out immediately below the greywackes, with the lithological characters of the *R.-maximus* band, and furnishing in excellent preservation its peculiar fossils, *Rastrites maximus*, *Monograptus runcinatus*, &c.

Fig. 17.—*Section in Eldinhope Burn.*



D. Flagstones, shales, and greywackes.
Cb. Grey shales with black and white seams, containing *Rastrites maximus* &c.
(2) Zone of *Monograptus spinigerus*. *f.* Fault.

All the central beds are hidden from sight by masses of boulder-clay and alluvium ; but on the north side of the arch a boss of black shale emerges, and affords one of the finest sections of the *M.-spinigerus* zone in the south of Scotland. About 20 feet of its beds are exposed, and show the peculiar cytheroid concretions, the Annelide-trails, the grey ashy seams, the reticulated laminæ, &c. we have learnt to look for in the zone, and afford a host of indifferently preserved examples of its concomitant fossils, *M. spinigerus* (Nich.), *M. tenuis*, &c.

To the north these beds pass under a shattered group of grey and black bands, with white-clay seams, which plunge below a fine cliff of flaggy greywackes.

Sundhope.—Some of the most fossiliferous beds of the *M.-spinigerus* zone are exposed on a small cliff on the side of the Yarrow, opposite the farm of Sundhope. Fossils are abundant, and, as is almost invariably the case with this zone, in a state of admirable preservation.

The flaggy greywackes are visible on both sides of the exposure ; but the intermediate beds are not exhibited.

(c) *Black Band of Ettrick and Glenkiln.*

i. *Ettrick River.*—The black-shale bands traced by us from the neighbourhood of St. Mary's Loch into the basin of the Ettrick are continued to the south-east for a few miles beyond the watershed ; but ultimately they subside, one by one, below the unbroken mass of greywacke in that direction. To this rule, however, there is one notable exception. The southern, or Berrybush, band, after disappearing for a short time near Cossar Hill, again emerges, and, sweeping in a gently curved line to the head of the valley of the Ettrick, is prolonged in numerous disconnected exposures of black shales as far as Glenkiln, near Dumfries. It demands especial notice here, as it not only affords several sections of the strata of the lowest division of the Moffat Series, but the determination of its relation to the so-called "axial" or "Ardwell" beds, which bound it on the south, has a most important bearing upon the general Silurian geology of the south of Scotland.

At Shorthope, which may be regarded as marking the easterly commencement of the band, only Birkhill Shales are visible. These are thrown into several parallel undulations. As usual, the most conspicuous beds are the flag-like shales of the *D.-vesiculosus* and *M.-gregarius* bands of the lower group. They are greatly indurated, and yield only occasional examples of *Diplograptus vesiculosus* (Nich.), *Climacograptus rectangularis* (M'Coy), *Monograptus tenuis* (Portl.), &c. The grey and black shales of the upper group have undergone even a larger amount of disturbance, but are easily recognized by their peculiar mineralogical characters and their relation to the surrounding greywackes.

At Brockhope the band widens greatly, and exposes the underlying Hartfell Shales, the "Barren Mudstone" occupying its natural position in the centre of the band.

Some of the deeper beds of the Hartfell Shales are visible at Phawhope, where for the first time we are presented with an exposure showing the Grey group passing below the greywackes to the north. To the south the same beds, with their characteristic white-clay bands and peculiar fossils, *Monograptus Halli* (Barr.), *M. spinigerus* (Nich.), lie distinctly between the greywackes and the black division of the Birkhill series in several localities.

Beyond Phawhope the band crosses the watershed into the head of Selcoth Burn, and forms one of the three bands of Craigmichan Scaurs, where its characters and relationships have been already described.

Everywhere along this extended line the axis of the anticlinal is so greatly inverted that the Upper Birkhill Shales seem to repose at a very small angle upon the greywackes to the south.

Two other anticlinals of Craigmichan are also partially visible in the Ettrick valley. The central arch crosses the river above Phawhope, but soon disappears.

ii. *Entertrona.*—The southern arch is best exhibited in the small burn called Entertrona, where beds of the Glenkiln division are abruptly collocated with the greywackes to the north, and yield *Leptograptus*, sp., *Didymograptus superstes* (Lapw.), *Dicellograptus divaricatus* (Hall), *Climacograptus cælatus* (Lapw.), *Diplograptus* (?) *bimucronatus* (Nich.), *Cœnograptus gracilis.* They are faulted against the upper or grey group of the Birkhill Shales, which show the black, white, and grey lines with which we are already so familiar. The fossils present include, among others, *Rastrites maximus* (Carr.), *Rastrites hybridus* (Lapw.) *Retiolites perlatus* (Nich.), *Monograptus runcinatus* (Lapw.). These fossiliferous strata dip steadily to the southward at a small angle, passing upwards into the barren flagstones and greywackes of Ettrick Pen.

iii. *Belcraig Burn* (Pl. XIII. Plan H).—Several exposures of the dark shales of this band occur in the heights to the south-west of

Craigmichan Scaurs, but no intelligible transverse sections are visible till we reach the lower portion of Belcraig Burn, a small stream falling into the Annan about 4 miles from the town of Moffat (fig. 18).

Fig. 18.—*General Section, Belcraig Burn.*

D. Flaggy greywackes with shaly partings.
Cb. Grey flaggy shales with lines of white clay and seams of black fossiliferous shale.
3. Zone of *Rastrites maximus.* 2. Zone of *Monograptus spinigerus.*
Ca. Black flaggy shales with seams of coloured mudstone. *Diplograptus vesiculosus* &c.
Bb. Mass of flaggy mudstones pale, non-fossiliferous.
Ba. Shattered slaty shales, with *Leptograptus flaccidus*, &c.
Ab. Pale shales and flaggy beds, with band of thin black pyritous shales yielding *Cœnograptus gracilis, Dicellograptus sextans*, &c. *f f f.* Faults.

Here the black and grey shales and mudstones of the Moffat Series are seen partly in the main stream, partly in the course of a small tributary which enters from the south. The chief axis of the master anticlinal into which the strata of the band are thrown is, as usual, greatly inverted, all the beds without exception dipping at a steep angle to the west-north-west.

The south-eastern side of the arch shows an ascending succession through the Birkhill Shales into the overlying greywackes: on the opposite side the latter are buried beneath the coarse conglomerate which here forms the basal bed of the Permians of Dumfries.

The Glenkiln Shales occupy the centre of the anticlinal. In the main stream they form a rude arch, and the only beds exposed are the black flaggy highly siliceous shales seen at Dobb's Linn. They afford *Didymograptus superstes* (Lapw.), *Dicellograptus sextans*, and a few other forms. In the side stream, the group is represented by the soft white and yellow beds of Craigmichan—barren, concretionary, or with cuboidal fracture—together with two soft black beds, much crushed, but affording numerous examples of such characteristic forms as *Didymograptus superstes* (Lapw.), *Cœnograptus gracilis* (Hall), *Dicellograptus sextans*, &c. &c.

To the north-west these Glenkiln beds are faulted against a mass of the "Barren mudstone" of Upper Hartfell age, which is admirably exposed in both streams. As no convolutions are visible, its thickness is apparently greatly in excess of that of the same zone in any other known locality. At the junction of the streams, the mudstone is underlain by a fragment of the *Pleurograptus* zone of the Lower Hartfell, with *Pleurograptus linearis* (Carr.), *Leptograptus flaccidus* (Hall), &c. The same zone recurs on the opposite side of the Glenkiln Shales, and affords similar fossils.

The Hartfell beds are faulted in their turn against the Birkhill

Shales, and of these there is here exposed the most complete section known to me as existing on the southern side of this band; and the proof it affords that the Ardwell beds stand in the same relationship to the Moffat Series as all the greywackes to the northward is indubitable and overwhelming.

Two small arches at the base of the group bring up the soft shivery shales of the *D.-acuminatus* band, with their characteristic fossils. These are followed by a great thickness of hard flaggy beds, showing in their upper portions the variegated mudstones of the *M.-gregarius* zone, and yielding in abundance *Diplograptus vesiculosus*, *Climacograptus rectangularis* (M'Coy), and, higher up, *Monograptus gregarius* (Lapw.), *Rastrites peregrinus* (Barr.), &c.

The lowest zones of the Upper Birkhill Shales are much broken; but the majority of their characteristic fossils may be collected.

The highest or *R.-maximus* division can be identified at a glance; the grey shales with black bands, the yellow and white clay seams, &c. are clearly shown and perfectly unaltered. The commonest fossils are *Rastrites maximus* (Carr.), *Monograptus Halli* (Barr.), *M. Hisingeri* (Carr.), and *M. runcinatus*, Lapw.

These strata are separated from the greywackes to the south by a few feet of shales and flaggy beds as in other localities, all the strata being inverted, and dipping to the north-west at an angle of about 45°.

On the opposite margin of the band, a few feet of the lowest portion of the grey group are visible in a small projection at the junction of the two streams. They swarm with beautifully preserved examples of *Diplograptus cometa* (Gein.), *Monograptus leptotheca* (Lapw.), &c. To the south-east these beds are faulted against the Hartfell Shales; to the north-west the remainder of the succession is obscured by turf and heather.

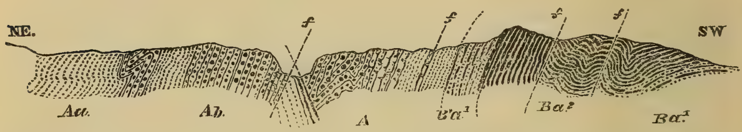
Duffkinnel.—Beyond Belcraig the Silurian rocks are buried beneath the coarse Permian deposits of the vale of the Annan. They again emerge in rolling ground near Raehills, and numerous indifferent sections are apparent in the banks of the various mountain-streams. The most important is that of Duffkinnel, where dislocated and altered Birkhill Shales swarm with beautifully preserved Graptolites.

iv. *Glenkiln Burn* (Pl. XIII. Plans F, G).—Continuing our course in the same general direction to the south-west, we finally reach the notable sections of Glenkiln Burn. The dark shales are here exposed in two distinct sections, which are divided from each other by a band of greywackes a quarter of a mile in width.

Lower Exposure (fig. 19).—The first of these sections occurs at the spot called Black Linn. With the exception of one small group of strata, all the beds exhibited belong to the lowest division of the Moffat Series. Of the beds of this division, indeed, this may be regarded as the typical exposure. They are here clearly separated from those of the succeeding divisions, and at the same time swarm abundantly with their characteristic fossils. Hence their special title of the Glenkiln Shales.

The physical arrangement of the Moffat rocks of this locality will be evident on a study of the accompanying plan (F) and sections. A small cliff at the southern extremity of the section exhibits a synclinal of Lower Hartfell Shale, broken by faults, but with its strata little altered. The central portions of the trough are formed of the hard flag-like black shales of the *Dicranograptus* zone, and afford its characteristic fossils, *Dicranograptus ramosus* (Hall), *D. Clingani* (Carr.). To the south beds of grey and black shale, with numerous flinty ribs, are exposed in the bed of the stream, clearly passing underneath the foregoing zone, and yielding in relief *Climacograptus Scharenbergi* (Lapw.), *C. Wilsoni*, &c., the commonest fossils of the lowest or *Climacograptus-Wilsoni* zone of the Hartfell Shales.

Fig. 19.—*Glenkiln Burn.* (Lower Section, *Black Linn.*)



*Ba*². Flaggy black shales with *Dicranograptus ramosus, Climacograptus caudatus,* &c.
*Ba*¹. Black slaty shales with ribs of grey rock. *Climacograptus Wilsoni,* &c.
A. Pale mudstones and dark shales with seams and beds of hard flagstone, much disturbed.
Aa. Pale shivery mudstones, contorted, non-fossiliferous.
Ab. Black shales with a few seams of grey flag. *Cœnograptus gracilis, Thamnograptus, Didymograptus,* &c. *fff.* Faults.

The northern side of the synclinal is inverted, and these beds again emerge in that attitude from below the *D.-Clingani* zone in the reverse order.

They are in contact with a thick group of shivery shales and mudstones, dull grey, brown, and black, with intercalated beds and bands of hard siliceous rock, from an inch to a foot in thickness. These beds are greatly faulted and broken, and are wholly destitute of fossils throughout. At the foot of the small stream entering from the northward they are followed abruptly by a thickness of 20 feet of black flaggy shales, crowded with fossils, principally *Cœnograptus gracilis* (Hall), *Cœnograptus surcularis* (Hall), *Thamnograptus typus* (Hall). These fossiliferous beds are beautifully exposed at the foot of the tributary stream, where they are seen to contain some of the peculiar grey ribs already noticed.

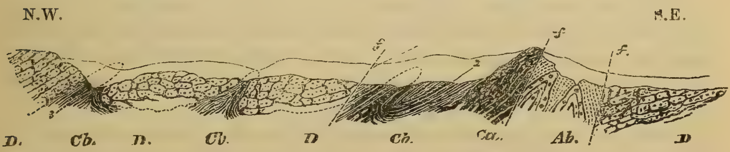
To the north-west they are succeeded by a great thickness of soft grey, white, or brown shivery mudstones, barren of fossils, dipping steadily up the little burn for nearly a hundred yards.

On the south bank of the main stream the peculiar dark shales and mudstones, with intercalated ribs of hard grey flagstone, fill up the whole section between the fossiliferous zone above mentioned and two contiguous bands of hard flaggy black shales, which are exposed in the sloping cliff above a deep shaft or bore-hole, unfenced and obscured by vegetation, marking the spot where some enterprising speculator, misled by the black colour of these rocks, has foolishly excavated them in search of coal. These shales yield an abundance of badly preserved Graptolites. The majority are identical with those of the black flags already described; but there occur in addition *Didymograptus superstes* (Lapw.), *Dicellograptus sextans* (Hall), *Dicranograptus formosus* (Hopk.), *Didymograptus serratulus* (Hall), &c.

To the northward the rocks exhibited at this locality must be faulted against the greywackes of the neighbourhood, which occupy the bed and banks of the stream for the succeeding quarter of a mile, beyond which we reach a second section of the rocks of the Moffat Series.

Upper Exposure (fig. 20).—The greywackes terminate, as abruptly as they commenced, against a mass of the Glenkiln Shales, which here form an irregular anticlinal, and yield numerous well-preserved fossils, identical with those occurring in the black flags at the junction of the two streams of our former exposure.

Fig. 20.—*Glenkiln Burn.* (Upper Section.)



D. Flagstones and greywackes, with partings of shale, grey and purple.
Cb. Grey and purple shales, with seams of black shale.
3. Zone of *Rastrites maximus.* 2. Zone of *Monograptus spinigerus.*
Ca. Black flaggy shales, with partings of variegated mudstone and clay.
Ab. Black shales, grey and white mudstones, &c., with *Dicranograptus ziczac*, *Thamnograptus typus*, &c. *fff.* Faults.

They are faulted in their turn against a highly contorted section of the Birkhill Shales. The lower beds of the latter are well exhibited in a naked cliff on the east side of the stream overlying the Glenkiln Shales, too shattered to yield more than a few of their characteristic fossils, but easily identified by their peculiar variegated seams of mudstone and clay. They are prolonged in the cliffs of the west bank, where they yield an abundance of well-preserved Graptolites. Here the *M.-spinigerus* zone and its associated beds are conspicuous, and furnish, as usual, exquisitely preserved examples of *Monograptus spinigerus* (Nich.) and *M. Hisingeri* (Carr.). The *R.-maximus* band is cut out in the bed of the stream at this point, but its fossils can be collected in the beds shown in the east cliff beyond. It rises again to the surface at the angle of the burn among the greywackes about 200 yards further to the northward, where it yields numerous examples of *Rastrites maximus* (Carr.), *Monograptus Halli* (Barr.), &c.

§ III. *Description of the Sections of the Moffat Series to the North of the Moffat-Yarrow Valley.*

In the great sheet of thick-bedded arenaceous strata out of which is carved the broad mountain ridge of Whitecombe and Hartfell, with its bounding valleys of Annandale and Meggatdale, a large number of exposures of the dark shales and mudstones of the Moffat Series are apparent. Judging from their geographical arrangement, it is tolerably evident that, as usual, they are disposed in several subparallel lines or bands, each of which will probably be found to mark the position of one of the more important anticlinals of the rocks of the region. In none of these bands have we the same clear evidence of continuity among the black beds as that furnished by the ground to the south of the Moffat valley. At the same time there are few individual sections so complete or satisfactory as the majority of those already described. Fortunately, however, our thorough acquaintance with the lithology and fossils of the various zones enables us to identify them almost at a glance; and, as their original sequence has been conclusively established, we can now afford to dispense with a large proportion of the confirmatory evidence so necessary in our preliminary investigations.

It will be seen from the general map of the district (Pl. XI.) that seven bands of dark shale are present to the north of the Moffat valley, viz. those of (1) Dobb's Linn, (2) Polmoody, (3) Frenchland, (4) Carrifran and Garple, (5) Auchencat Burn, (6) Hartfell Spa, and (7) Headshaw Linn.

It will be needless to describe each of these with the same care as that we have bestowed on the typical bands to the south of the Moffat-Yarrow valley. Indeed, from the very doubtful continuity at the surface of the strata of which these bands are composed, the same method of treatment is obviously inapplicable. In this case it will be more satisfactory if we describe in brief the chief exhibitions of the dark shales, and give such a general account of the remainder as may suffice to make it clear that, in the northern half of the Moffat district, the zones and fossils of the Moffat Series are identical with those in our former sections, and that they stand in precisely similar stratigraphical relations to the neighbouring greywackes.

For this purpose we may conveniently regard the present region as being composed of the three areas drained respectively by (1) the Annan and its chief tributary, the Evan, (2) the water of Meggat, and (3) the Moffat water.

The best sections are found in the first-named area, those least satisfactory (with the notable exception of Dobb's Linn, already described) in the area drained by the Moffat water.

(a) *Basin of the Upper Annan.*

i. *Frenchland Burn* (Pl. XIII. Plan E).—One of the most intelligible exposures of the Birkhill Shales to the north of the Moffat valley is visible along the lower course of the small stream called Frenchland Burn. The section at this locality possesses an additional interest for geologists from the circumstance that it was the only section of the Moffat Series examined personally by Sir Roderick Murchison. He described the general appearances of the pyritous mudstones and the surrounding greywackes with some minuteness, noticing especially their greatly disturbed condition, but carefully refrained from hazarding any opinion as to their interrelationships. (Q. J. G. S. vol. vii. p. 161.) With our present experience we can now unravel the succession with comparative ease and certainty.

From the point at which the black shales emerge from below the Permian conglomerates of the vale of the Annan to that where they finally subside beneath the flagstones and greywackes of the Gala group is about three fourths of a mile. Midway between these points, however, the greywackes occupy the stream-course for a distance of about one fourth of a mile, so that there are actually two separate exposures of black shales. The general direction of the stream is almost coincident with the strike of the rocks, and consequently only a very small proportion of the whole of the Moffat Series is exposed. On both sides the greywackes approach nearly to the bottom of the hollow, the black shales being confined to the bed and banks of the burn.

The two exposures show precisely the same succession, viz. all the Birkhill Shales above the zone of *Diplograptus acuminatus*; but the lower exposure affords the most satisfactory sections of the beds, while the upper yields the more numerous fossils.

In the lower exposure the beds, which are highly contorted, show the usual irregular but prevailing dip to the N.N.W. Their arrangement may be gathered from the accompanying plan. Some hard black flags near the centre of the exposure yield *Diplograptus vesiculosus* and its associates, and pass into softer and more pyritous strata, which in their turn are in contact with the grey and black shales of the Upper Birkhill group. To the south the latter are inverted, but are seen to pass gradually into the overlying greywackes. To the north, where a small waterfall marks the summit of the formation, a small fault occurs, and the dark seams here are highly fossiliferous, and yield beautifully preserved specimens of such characteristic forms as *Monograptus Becki* (Barr.), *M. Halli* (Barr.), *M. Hisingeri* (Carr.), and *Diplograptus folium* (His.).

The higher exposure adds nothing to our physical evidence, but furnishes us with an abundance of Birkhill fossils. To the south its beds are faulted against the greywackes; to the north the point of junction is not visible. They dip almost invariably to the N.N.W., but are, in truth, arranged in several inosculating anticlinal forms. In all, the predominating strata are those of the Lower Birkhill Shales; the peculiar pyritous beds of the *M.-gregarius* zone are especially conspicuous, swarming with their characteristic Graptolites. The grey-shale group is also visible for some distance; but only a few of its fossils have been obtained.

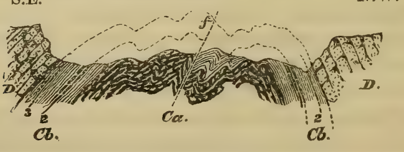
ii. *Garple Spa* (Pl. XIII. Plan J).—To the west of the valley of the

Annan the Moffat Shales are exposed in a deep gorge lying along the course of the Garple Water, a small tributary of the Evan. Deep, narrow, and overhung with a thick growth of trees and underwood, the picturesque little glen is a favourite resort of tourists and pleasure-seekers. The burn toils between perpendicular cliffs of the hard grits and greywackes of the Gala group, more than ordinarily coarse and massive, and weathering of a dull purple colour. About half a mile from the mouth of the gorge the grits retreat from the edge of the stream, which here flows through a narrow haugh of alluvium, and lays bare in its course several capital exposures of the highest division of the underlying Moffat Series.

The most ancient strata visible at this spot belong to the *D.-vesiculosus* zone of the inferior division of the Birkhill Shales. They form a low arch, the axis of which crosses the course of the stream at a very oblique angle. This arch is conspicuously exhibited at the point N. of the plan, in the north bank of the stream. Two small exposures of the overlying beds are apparent a little below. In that on the southern margin of the burn a partially inverted section shows the junction of the Lower and Upper Birkhill Shales. The latter are the grey flaggy shales and dark seams of the lower beds of the *M.-spinigerus* zone, with white-clay bands and calcareo-ferruginous nodules. Fossils are abundant and in good preservation, principally *Monograptus Hisingeri* (Carr.), *M. Clingani* (Carr.). A small section on the opposite side of the stream exposes grey and black shales somewhat higher in the vertical series.

In the prolongation of the axis of the main anticlinal to the south-west, a highly fossiliferous exposure of the *M.-gregarius* zone is visible in the south bank of the stream. The strata are greatly disturbed; but their soft, highly pyritous nature, and the numerous intercalated seams of variegated mudstone, enable us to identify them at first glance with the corresponding beds of Dobb's Linn. They yield excellent specimens of *Rastrites peregrinus* (Barr.), *Monograptus gregarius, M. leptotheca* (Lapw.), *M. cyphus* (Lapw.), *M. lobiferus* (M'Coy), *M. intermedius* (Carr.), *Diplograptus palmeus* (Barr.), *D. tamariscus* (Nich.).

Fig. 21.—*Garple Linn.*



D. Thick-bedded purple grits and flags.
Cb. Purple and grey shales with black seams.
3. *Monograptus Halli.* 2. *M. spinigerus.*
Ca. Contorted black flaggy shales with partings of variegated mudstone. *M. triangulatus*, &c. *f.* Fault.

About a hundred yards above this point the stream suddenly turns at right angles to its former direction and lays bare a complete transverse section of the Moffat beds of the locality (fig. 21). In spite of the convoluted state of many of the beds, the arrangement of the black shales is easily interpreted, and is demonstrative of the infraposition of the Birkhill beds to the neighbouring greywackes. To the north the latter form a steep cliff, beneath which the purple shales of the *R.-maximus* zone, here barren of fossils, plunge at a very steep angle. Below these the grey and black shales of the *M.-spinigerus* zone are recognizable. A few of its black bands are here very prolific, swarming with multitudes of *Monograptus spinigerus* (Nich.), *M. Hisingeri* (Carr.), *Retiolites perlatus* (Nich.), *Diplograptus Hughesi* (Nich.), &c.

Similar beds, greatly disturbed, form the floor of the stream for some distance. The lowest grey band is much hardened, and where it finally disappears gives rise to a small waterfall, beyond which the underlying *M.-gregarius* zone comes to the surface. Its beds form the north bank of the stream above the cascade. It is highly interesting to note the presence in its central division of the thick seam of ironstone nodules so conspicuous at Dobb's Linn. Here also the soft pyritous mudstones which are immediately in contact with it swarm with *Monograptus triangulatus* (Harkn.), *Diplograptus modestus* (Lapw.).

The overlying *M.-spinigerus* zone of the Upper Birkhill Shales is much more disturbed than it is on the opposite leg of the anticlinal, but it may be identified both by mineralogical characters and by fossils. The beds of the succeeding purple-shale zone, on the other hand, are admirably exhibited. They dip steadily below the thick-bedded greywackes of the south cliff at a small angle, and yield a few characteristic fossils, preserved with their full relief.

iii. *Rittonside.*—Higher up the valley of the Evan, viz. at Middlegill, Rittonside, and Headshaw, there are additional exposures of the dark shales. The first of these is almost valueless for our present purpose; but at Rittonside a fairly intelligible section is afforded by the walls of the railway-cutting above the small cottage. Here, as at Belcraig, the Graptolitiferous beds are traversed by an enormous dyke of greenstone, and are greatly shattered. In the centre of the section the hard black flags of the *D.-vesiculosus* zone are apparent, and furnish, among others, *Diplograptus vesiculosus* (Nich.), *Climacograptus scalaris* (His.). On both sides they are followed by faulted wedges of the pyritous and variegated shales of the succeeding *M.-gregarius* zone, replete with *Monograptus gregarius* (Lapw.), *Diplograptus tamariscus* (Nich.), and their usual associates. Between these and the hard greywackes of the remainder of the cutting are some fragmentary patches of purple and grey flaggy beds, which represent the highest or "grey" division of the Birkhill shales.

iv. *Headshaw Linn.*—The dark beds are here exposed in the normal score or gorge dug out by the waterfall marking the junction of the Gala and Moffat formations. The majority of the beds are intensely metamorphosed, being changed into a soft flaky mass of a deep purple colour. A small boss of unaltered strata at the entrance to the gully shows the soft pyritous beds of the *M.-gregarius* zone, with their lines of variegated mudstone and yielding good examples of *Monograptus cyphus*, *M. gregarius* (Lapw.), *Diplograptus tamariscus* (Nich.), *D. folium* (His.).

To the north the flagstones and greywackes of the country are underlain by a band of 4 or 5 feet of purple shales, which reposes at once upon the *M.-gregarius* zone. On the south side of the section a much greater thickness (about 30 feet) of these purple shales occupies a similar position.

v. *Hartfell Spa* (Pl. XIII. Plan K).—Three miles to the eastward of Rittonside we reach the magnificent exposure of Hartfell Spa. At this locality the Moffat Shales occur in the broad mound called Arthur's Seat (2398 feet), which forms the south-western buttress of the mountain of Hartfell (2600 feet). In the flank of this mountain an enormous gash has been eroded, about a quarter of a mile in length and from two to three hundred feet in depth, which forms a striking feature in the view of the ridge for many miles to the south-east. The name of the spot is derived from a mineral spring which rises among the dark shales in the centre of the exposure, and which has long been celebrated for the strength and efficacy of its waters.

The black shales of the Hartfell band here rise to the surface in an elongated ellipse, or narrow lenticle, about three miles in length. It is about a quarter of a mile in diameter at its centre, thinning away almost to a point at its opposite extremities. It is formed by a single master anticlinal of the Moffat Series, composed of numerous subordinate and very irregular arches. Nowhere to the north of the Moffat valley are the dark shales so greatly folded and shattered as in this locality; but, on the other hand, nowhere are the fossils so prevalent throughout the beds; so that the deficiencies in the stratigraphical evidence of the sequence of the strata are amply compensated by the extra facts derived from palæontological considerations.

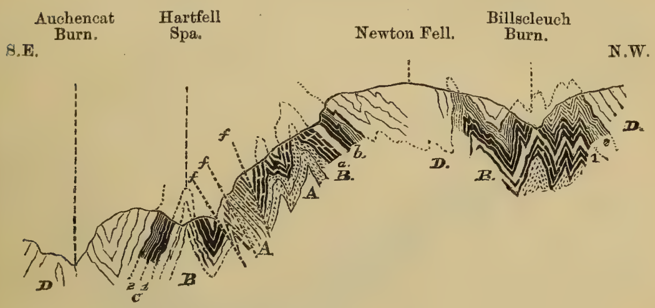
Birkhill Shales.

As in all our former sections, the highest beds rise from below the greywackes at the extremities and along the inner margin of the ellipsoid. At its south-westerly extremity the stream has cut the narrow gorge known as Frizzle's Linn, generally along the line of junction of the grits and mudstones. To the north of the stream at this point the grits are visibly in conformable contact with a thin group of drab, grey, and black shivery mudstones, similar to those of Rittonside and Headshaw Linn, but in a perpendicular or even slightly reversed attitude. Fossils are numerous, but indifferently preserved, viz. *Monograptus gregarius*, *M. tenuis* (Portlock), and *Dawsonia campanulata* (Nich.).

The stream occupies a similar position with respect to the underlying rocks as far as the foot of the Spa Score, and affords at least two additional sections of the higher zones of the Moffat Shales.

The first of these exposures occurs at the Old Copper-mine; here a horizontal shaft runs from the level of the stream into the flank of the steep ridge to the southward, and exhibits a small section of shattered Birkhill Shales, faulted against thick-bedded grits, off which they dip, apparently to the northward, at steep angles. The black shales are much contorted and stained with the green carbonate of copper, the presence of which originally led to mining-operations at the spot. The fossils obtainable are those of the *M.-gregarius* zone, viz. *Monograptus gregarius* (Lapw.), *M. tenuis*, *Diplograptus tamariscus* (Nich.), and a few others.

Fig. 22.—*General Section through the Hartfell exposure.*



D. Greywackes and flagstones.
B. Birkhill shales: 2. Upper; 1. Lower.
B. Hartfell shales: *b.* Upper; *a.* Lower.
A. Glenkiln shales. *ff.* Faults.

The second exposure is met with about 200 yards higher up the stream. The black shales, which are here pierced by a small felstone dyke, show the nodules and variegated mudstones of the higher *M.-gregarius* zone, and yield in some abundance *Monograptus gregarius* (Lapw.), *M. fimbriatus* (Nich.), *M. lobiferus* (M'Coy), *Diplograptus vesiculosus* (Nich.).

In the Spa Score itself, immediately above the mineral spring, the greywackes cap the south cliff for a long distance, and are either in a perpendicular attitude or dip steeply to the south-east. They are immediately underlain by a few feet of shattered shale and mudstone, much wrinkled, and weathering of a pale orange colour, but exhibiting several conspicuous seams of white-clay shale. These form the summit of a great mass of highly contorted black shales and flags, pierced by dykes of felstone. In spite of their greatly shattered and, indeed, more or less altered character, we easily recognize the zone of *Monograptus gregarius*, with its characteristic variegated mudstone seams; and two long parallel rows of hard black flags projecting above the general face of the cliff from end to end are immediately assigned to the *D.-vesiculosus* band. The strata are so convulsed that it would be impossible to lay down any line of demarcation between the various zones, and the included fossils are consequently placed here in a single list.

Monograptus gregarius (*Lapw.*).	Diplograptus vesiculosus (*Nich.*).
—— leptotheca (*Lapw.*).	—— folium (*His.*).
—— cyphus (*Lapw.*).	—— acuminatus (*Nich.*).
—— tenuis (*Portl.*).	—— modestus (*Lapw.*).
—— communis (*Lapw.*).	—— tamariscus (*Nich.*).
—— attenuatus (*Hopk.*).	Climacograptus normalis (*Lapw.*).

It will be apparent that here, as everywhere to the north of the Garple Band, none of the Upper Birkhill fossils are present.

Along the north-western margin of the ellipsoid the same Birkhill Shales clearly constitute its marginal beds, passing below the succeeding flagstones and greywackes.

In Billscleuch there is an exposure of these strata about half a mile in length (fig. 22). They form two distinct subordinate anticlinals, separated from each other by a narrow patch of greywacke. The shales are perhaps less shattered than those in the Spa Score, but are much more intensely altered. The lowest strata seen are certain pale shales coming into the place of the Barren Mudstone of the sections to the south of the Moffat valley. Certain hard flaggy beds which succeed probably represent the zones of *D. vesiculosus* and *M. gregarius*. One band only is fossiliferous; it contains *Monograptus cyphus* (Lapw.) and *Diplograptus tamariscus* (Nich.).

The grey flagstones and shales of the Upper Birkhill Shales certainly occupy much of the section between this unaltered band and the greywackes. Beyond the fact that many of the highly altered pale or cream-coloured beds show occasional seams of milk-white mudstone no reliable evidence of their presence is obtainable.

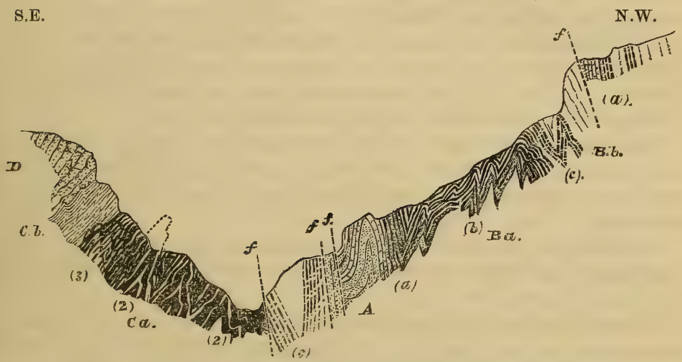
In Potburn, half a mile to the north-eastward, a similar group of beds is visible. The strata are here less altered, and the majority of the Lower Birkhill Graptolites are present.

The shivery mudstone that everywhere underlies the greywackes forms the extreme north-easterly point of the ellipsoid at the head of Blackshope Burn, the surrounding cliffs showing the massive gritstone of the Gala group. In the very centre of the ellipsoid, midway between the Spa Score and that of Billscleuch, a patch of greywacke occurs on the ridge. Its northern margin is not exposed, but its southern limit can be made out for about 200 yards above the cliffs of the gorge. The grits dip to the southward at an angle of about 40°; and there comes out from below them a band of grey shales greatly indurated, representing the upper portion of the Birkhill Shales. Along the south-western margin of this patch the pyritous and flaggy black shales of the zones of *M. gregarius* and *D. vesiculosus* are visible at the head of some small trough-like scores, and yield indifferently preserved Graptolites of the characteristic species *Monograptus gregarius* (Lapw.), *M. tenuis* (Portl.), *Diplograptus tamariscus* (Nich.), *D. vesiculosus* (Nich.).

Hartfell Shales.

Nowhere throughout the whole of the Moffat district or, indeed, in any single locality in the south of Scotland, is there to be seen so magnificent an exposure of the black flaggy beds of the middle division of the Moffat Series as is exhibited in the northern cliffs in the score at Hartfell Spa (fig. 23). It is for this reason that I have grouped the whole of the beds of this division under the general title of the Hartfell Shale, though the higher or Barren-Mudstone subdivision is far less conspicuous than in the sections to the south of the Moffat valley, and the terminal or *D.-anceps* band can nowhere be recognized.

Fig. 23.—*Section through the upper end of Hartfell Score.*



D. Grits and flagstones. *Cb.* Grey shales with white seams, shattered.
Ca. Black flaggy shales, with (3) *Monograptus gregarius,* (2) *Diplograptus vesiculosus, D. acuminatus,* &c.
Bb. Pale non-fossiliferous mudstones.
Ba. Black slaty shales. (*c*) Zone of *Pleurograptus linearis.* (*b*) Zone of *Diplograptus Clingani.* (*a*) Zone of *Climacograptus Wilsoni.*
A. Pale shales with hard grey and flinty ribs, non-fossiliferous. *fff.* Faults.

Much of the ground within the glen is too complicated ever to be perfectly mapped; but the general arrangement of the rocks can be easily made out. The disposition of the more important zones is given in the accompanying plan and sections (Plan K, Pl. XIII.; sections figs. 22, 23).

Roughly speaking, the Moffat beds of the glen are arranged in five subparallel anticlinal forms.

The axis of the first fold crosses the stream-course obliquely below the mineral spring. The lowest beds brought to the surface are those of the *Dicranograptus-Clingani* zone of the Hartfell Shale. To the south the strata of this anticlinal are faulted against the greywackes of the south cliffs; to the north they pass up into the Birkhill Shales already described.

The axis of the second or main anticlinal of the glen runs parallel with the central portion of the bottom of the gorge from end to end.

As in numberless instances in the Moffat district, the line of the axis is coincident with that of a longitudinal fault, which here lets in a long, thin, and crumpled wedge of Hartfell Shales between it and the fault bounding the Birkhill beds of the southern cliffs. To the north of the faulted axis excellent sections of the Lower Hartfell Shales are seen in the northern cliffs, crowded with their characteristic fossils, but highly convoluted. The axes of all the small folds which can there be detected rise to the north-east; and two are of sufficient importance to again bring up to the surface the higher beds of the Glenkiln Shales.

A third anticlinal of some importance is shown at the north-eastern summit of the north cliff, which also exposes a few feet of the underlying Glenkiln Shales. The axes of all these anticlinals, principal and subordinate alike, are usually faulted, so that in each case only a single leg of the arch is complete at the surface.

The beds of the lowest of the Hartfell zones, that of *Climacograptus Wilsoni*, are beautifully exhibited immediately above the lines of the Glenkiln Shales; but the best localities for fossils are those at the extreme ends of the most southerly line.

The hard black flags of the zone of *Dicranograptus Clingani* occupy much of the north cliff, in the lower portion of which they may be studied with ease, or in the lateral score near the head of the gorge.

The thin slaty shales with *Pleurograptus linearis* are best exhibited near the westerly termination of the north cliff, below the fault marked upon the plan.

The pale beds of the Barren Mudstone make but a poor figure in the sections at this locality. If the orange-coloured mudstones that are exposed between the zones of *Pleurograptus* and *D. vesiculosus*, as shown at the back of the little building erected over the mineral spring, include all the beds of this subdivision, it has dwindled down to at least half the thickness it possessed at Dobb's Linn. Similar beds are visible above the *Pleurograptus* zone, towards the summit of the northern cliffs near the Glenkiln bands marked upon the plan; and small patches of the same strata are discernible in several other localities.

The mineral characters and fossils of these zones will be given in the second portion of this paper.

Glenkiln Shales.

A few feet only of the barren portion of the Glenkiln Shales are all that are exhibited at this locality. The hard flinty band at the summit forms a rude cornice or projection running along the western base of the north cliff. It is seen in the same stratigraphical position in all the remaining anticlinals, and reposes upon several feet of dark grey and pale yellow mudstones identical with those of Glenkiln and Berrybush. It is impossible to separate them by the eye from those of the Barren-mudstone division of Upper Hartfell age; many of the shales exhibited at the head of the lateral score may belong to either subdivision.

(b) *Basin of the Meggat.*

The five exposures apparent in the valley of the Meggat possibly indicate the presence of two parallel bands of the Moffat Shales. It is very doubtful whether they have any definite relation to the anticlinals already described.

Syart-Law Score.—The largest exhibition of the black shales in this area is found in a deep gash or score in the northern flank of Syart Law, opposite the farmhouse of Cramalt. The beds visible are chiefly those of the Lower Hartfell Shales. They are greatly disturbed and altered. The most fossiliferous seam belongs to the central portion of the zone of *Dicranograptus Clingani.* It affords good examples of *Lasiograptus margaritatus* (Lapw.), *Diplograptus foliaceus* (Murchison), *D. truncatus* (Lapw.), *Dicranograptus ramosus* (Hall), and *Dicellograptus Forchhammeri* (Geinitz) in several varieties.

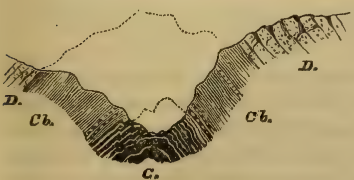
The higher portion of the zone of *Pleurograptus linearis* is also fossiliferous, yielding numerous specimens of *Diplograptus quadrimucronatus* (Hall), *Leptograptus flaccidus* (Hall), &c.

Craigierig.—About half a mile distant from the former locality, and in the prolongation of the strike of the rocks, the highest beds of the Lower Birkhill Shales are shown in the small stream at the back of the shepherd's cottage of Craigierig. Only a few feet of the fossiliferous portion of the dark shales are visible. They yield admirable examples of *Monograptus lobiferus* (M'Coy), *Diplograptus sinuatus* (Nich.), *D. tamariscus* (Nich.), and *Rastrites capillaris* (Carr.).

Similar beds are seen on the opposite side of Syart-Law Score, in the burn of Shielhope (see map, Pl. XI.).

Boar Cleuch (fig. 24).—A small but very important section of the black shales occurs in the gorge of the Boar Cleuch, a tributary of the Glengaber. The lowest beds visible in the floor of the gully are the hard black flags of the zone of *Diplograptus vesiculosus.* They are covered on both sides by the softer strata of the *D.-gregarius* zone, with their peculiar pyritous and variegated mudstones, containing scattered examples of *Monograptus gregarius* (Lapw.), *Diplograptus folium* (His.), *Dawsonia campanulata*, &c.

Fig. 24.—*Section of Boar Cleuch, Glengaber Burn.*



D. Coarse grits and flagstones.
Cb. Grey and purple flags and shales, non-fossiliferous.
Ca. Flaggy black shales with seams of coloured shales. (*Monograptus gregarius*, *Diplograptus vesiculosus*, &c.)

The peculiar shattery band at the summit of the zone passes below a thickness of 60 or 70 feet of hard grey flaggy shales, which graduate upwards into the coarse greywackes of the country. From their position in the section there cannot be the slightest doubt that these flaggy shales are actually the upper or grey division of the Birkhill Shales of our typical localities of Dobb's Linn and the bands to the south of the Moffat-Yarrow valley. The dark fossiliferous shales and the peculiar white-clay bands have gradually vanished as we have followed the Moffat Series to the west and north to this spot, where scarcely a single trace of them remains.

The section has a further value in affording a perfect demonstration of the inferiority of the Moffat Series of the Meggatdale to the surrounding greywackes, many of which are very different in their general features from those of the southern region.

(c) *Basin of the Moffat Water.*

The typical section of the Moffat Series of Dobb's Linn, which occurs at the head of the Moffat, has been already described. The remaining sections in this area may be dismissed in a few words.

Polmoody.—A short but continuous band of black shale runs from the hamlet of Polmoody in Moffatdale towards the head of Winterhope. The only strata visible along its course are the Birkhill Shales. In the Tail Burn they yield their characteristic fossils in relief. In the scores above Polmoody their highest beds can be seen in contact on both sides with the greywackes.

Carrifran.—A second band crosses the three parallel streams of Blackshope, Carrifran, and the Midlaw Burn. In Blackshope the strata are frightfully shattered; in Carrifran the fossils of the *Dicranograptus-Clingani* zone may be collected from the dark shales in abundance. In the exposure in the mountain of Whitecombe, the grey division of the Birkhill Shales may be seen in conformable contact with the greywackes.

Bodsbeck.—A single apparition of the Birkhill Shales occurs at the spot marked on the map (Pl. XI.) upon the south side of the Moffat Water.

Shortwoodend, &c.—The highest Birkhill beds pass below the greywackes at Shortwoodend, not far from the bottom of the valley. Traces of similar fossiliferous Birkhill beds have been detected by myself at the other localities indicated.

§ IV. *Summary of Observations and Conclusions regarding the Physical Relations of the Moffat Series.*

We have now completed our examination of the sections of the Graptolitic shales and mudstones seen within the limits of the Moffat district. The details brought forward in the preceding pages or inserted upon the accompanying plans and sections, place it wholly beyond question that in all the localities mentioned the various groups of the dark shales stand in corresponding natural relations to each other, and in the same physical attitude with respect to the surrounding greywackes. In spite of the excessive disturbance, fracture, and more or less alteration which these strata have undergone, the physical, mineralogical, and palæontological evidences at our command make it clear that in every intelligible section the natural sequence of the beds is identical with that in our typical section at Dobb's Linn. To the south of the Moffat valley this agreement is so exact that the sections can be compared bed for bed and fossil for fossil. To the north of the Moffat valley the dark fossiliferous seams gradually die out of the highest grey-shale group, which towards the north-west degenerates into a group of barren flagstones, undistinguishable from those which alternate with the surrounding greywackes.

So distinct and persistent, however, are the generality of the various Graptolitiferous zones in their essential characters, lithological and palæontological, that, as we have seen, they admit of immediate identification in every locality where they have not undergone excessive metamorphism. By an examination of their physical arrangement in numerous transverse sections, and by tracing them from point to point along the line of strike, we have assured ourselves of the fact that in every extended band of black shale, after the effects of the numerous faults have been allowed for, the order of the beds on both sides of the central line of the band is precisely similar. Where the main axis of the band is uninverted, the terminal zones on the opposite margins pass visibly below the surrounding greywackes. Broadly speaking, where the black-shale band is of small diameter, only the higher beds of the Birkhill Shales are apparent. As it increases in width the underlying zones emerge one by one in its centre; until finally, in the widest exposures, we meet with the deepest visible strata of the Glenkiln Shales.

We have, in addition, not only been able to satisfy ourselves of the fact that all the rocks of the district have been crumpled up in a large number of inverted folds, but we have even found it possible to trace the geographical position of several of these plications, and to measure approximately the amount of inversion. We have ascertained that this inversion is sometimes so intense that, as in the case of the Ettrick band, the overturned strata overhang the vertical to such an extent that at first glance they appear to be almost flat; at other times it is so variable in its direction that, as in Dobb's Linn, the plane of the inverted anticlinal oscillates as much as 30° on opposite sides of the perpendicular in less than 200 yards.

While therefore, on the one hand, the facts now at our command make it clear that all evidence derived from broad views of the apparent order of superposition of the strata within the present district, unless confirmed by other testimony, is not only useless but misleading, yet, on the other hand, they are amply sufficient to enable us to disentangle the complicated succession among the Moffat Shales themselves, and to establish the general identity of the surrounding and overlying greywackes.

The more important conclusions to which these facts inevitably lead us may be very briefly summed up as follows:—

1. All the black Graptolitic shales of the Moffat district are actually portions of one and the same continuous deposit.

2. They owe their repetition to a series of subparallel folds, the upper arches of which have been denuded (fig. 25).

3. They rise invariably from below the surrounding greywackes in anticlinal forms, the axes of which are usually inverted.

4. The deposit to which they belong is consequently the oldest rock-group in the Moffat district.

5. This fundamental rock-group, which is denominated by us the Moffat Series, is composed of a comparatively homogeneous assemblage of dark Graptolitic shales and pale barren mudstones.

6. Its collective thickness within the limits of the present district is about 300 feet, but its actual base is nowhere visible.

7. It falls naturally into three primary *divisions*, each of which is characterized by a special fauna, made up almost wholly of peculiar species.

8. Each of these primary divisions is again naturally subdivided into several *zones*, individually distinguished by special mineralogical and palæontological characteristics.

In the light of these results the difficulties hinted at in the early part of this paper wholly disappear.

The varying width of each of the longer shale-bands, its rapid contraction near its extremities, and its final disappearance, together with the peculiar boat-like form of the shorter exposures and their moniliform geographical arrangement, were all facts utterly inexplicable either upon the theory that the black shales occurred on

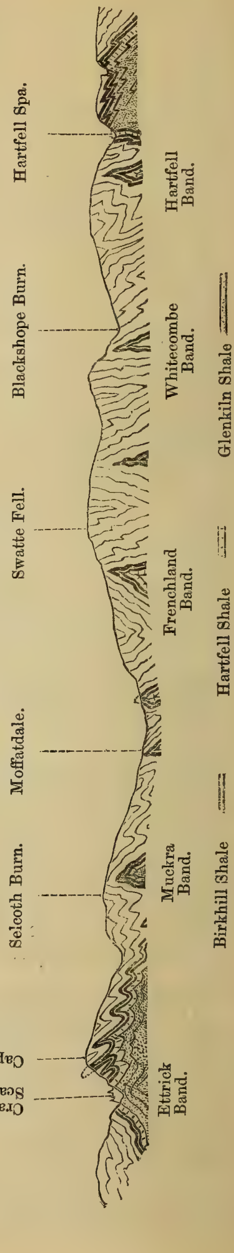


Fig. 25.—*General Section through the Moffat District.*
(Scale 1 inch to the mile.)

several distinct horizons in the great greywacke formation, or on the more popular hypothesis that they belonged to a single and persistent sheet, both underlain and overlain by arenaceous beds. They now find their common explanation in the simple circumstance that the dark shales reach the surface of the country along the chief anticlinal lines, the width of the several exposures being dependent merely upon the varying elevation of the crown of the arch.

The extraordinary diversity apparent in the various groups of species yielded by the strata of the same band in the different exposures along its course, and the peculiar localization of some of its most distinctive fossil forms, are quite as easily explained by our discovery of the rigid restriction of the Graptolitic species to definite zones. Not only do the earliest zones of each band make their appearance as a rule only in the widest exposures, but its apparent fauna in any single locality is necessarily that of the collective faunas of the special zones, which the concurrent accidents of plication, metamorphism, and denudation have there left accessible to the investigator. Lastly, we have no longer any room for astonishment at the remarkable similarity in lithological characters, the great lateral extension, persistent north-west inclination, and apparently gigantic thickness of the interminable greywackes of the Moffat district. We are now satisfied that they form in reality a single group of beds of no great vertical dimensions, the same strata being repeated again and again in rapid and partially inverted undulations.

B. Subdivisions, Lithology, and Palæontology of the Moffat Series.

§ I. *The Glenkiln Shales.*

From the foregoing description of the several sections of the Moffat Series within the limits of the present district it is evident that we are far from possessing an equal knowledge of the rocks and fossils of each of its three chief divisions. The general lithological and palæontological characteristics of the Birkhill division may be gathered from at least fifty different sections. The total number of appearances of the Hartfell Shales cannot exceed ten or twelve. Of the lowest division, or Glenkiln Shales, there are only five exposures, and in these the strata exhibited are mere fragments of the succession, cut off as a rule by slips or faults from all their original associates.

Naturally, therefore, our present knowledge of the Glenkiln division is far inferior in amount and accuracy to our knowledge of the overlying divisions. From the circumstances of the case we are unacquainted with any thing that ought properly to be regarded as the base of the division in this district. We are, however, able to determine with precision its superior limit, and at the same time to prove that in vertical extent it equals the succeeding divisions, and is characterized by a fauna correspondingly distinct.

The name of the division is derived from the burn of Glenkiln, near Dumfries, where its fossiliferous bands are most fully exhibited, and where they yield their fossils in the greatest variety and abundance. The succession is, however, there greatly interrupted by numerous faults which, running along the strike of the beds in a mass of very similar deposits, are almost impossible to detect. We are, unfortunately, unable to indicate any locality in the Moffat district where there is an absolutely uninterrupted sequence. The evidence for the order here given is partly physical, partly palæontological; it is consequently open to such slight corrections and additions as may be found to be necessary when the corresponding deposits in the Lammermuirs, Lead Hills, and Galloway are fully described.

At Hartfell (fig. 27, p. 309) the summit-bed of the Glenkiln Shales is seen to be formed of 4 feet of hard flaggy rock. This reposes upon a seam of dark shivery mudstone 8 feet in thickness, which passes in its turn into a group of pale yellow or orange-coloured shattery mudstones of indeterminable thickness.

At Craigmichan (fig. 3, p. 263) the same flaggy band is recognized in a corresponding position, supporting the main mass of the Hartfell Shales, and surmounting similar dark-gray and orange-coloured mudstones. Although only one or two insignificant faults are actually to be detected in the cliff below, yet no two sections, measured from the grey band into the heart of the Glenkiln Shales, are precisely alike. In each section we recognize a thickness of from 40 to 60 feet of barren shales of a peculiar character, apparently interposed between the highest visible black-shale bed of the Glenkiln group and the lowest black-shale band at the base of the succeeding Hartfell division (fig. 3). The evidence derived from other exposures of these strata, however, renders it almost certain that they constitute in reality the lowest visible subdivision of the Glenkiln Shales, being actually inferior in geological position to the apparently underlying black beds, which are cut out above by the faults seen near the base of the Hartfell Shales.

The majority of the beds composing the lower Glenkiln subdivision are thin-bedded shales, often finely laminated. A few show a tendency to run into concretionary forms, and occasionally weather down into irregular ellipsoids, exteriorly of a yellow or rusty orange-colour. Some are shattery mudstones, breaking up into small prismoidal splinters. Others, again, are coarser in their texture, and have a rough harsh surface; and where greatly hardened split up into thick plates with a rugged uneven face, as in many bedded traps and ashes, to which, indeed, in other respects several of these beds bear no inconsiderable resemblance. All these strata, as might, indeed, have been inferred from their mineralogical character, are totally barren of true fossils; but many are pierced in all directions by worm-burrows and the like.

The most striking feature of these barren beds is the presence among them of seams of hard flagstone, varying in thickness from a few inches to more than a foot, and occurring in definite layers sometimes 6 feet in depth. Occasionally argillaceous, they are more frequently highly siliceous, and break under the hammer with a conchoidal fracture. Rarely, indeed, do they show any clear evidence of internal lamination, but ultimately break up under the influence of the weather into large cuboidal fragments. From their intractable character, especially when slightly metamorphosed, they form conspicuous "ribs," or projecting bands, rising above and protecting the easily weathered surfaces of the soft shales in which they are imbedded. They are rarely absent in any of the sections of the Glenkiln Shales of the Moffat area, but nowhere are they so conspicuous as in the Craigmichan exposure, where they run along the basal portions of the cliff to the north of Selcoth Burn for a distance of nearly half a mile.

In the same section, apparently below the "ribbed shale" group, we observe two distinct seams of black shales, which, with certain white or very pale-coloured mudstones and flaggy beds, occupy the central portions of the exposure. The higher black band is 6 feet in thickness, consisting of hard ringing laminæ of carbonaceous shales, some of the softer faces of which show *Diplograptus tricornis* (Carr.), *D. foliaceus* (Murch.), *D. perexcavatus* (Lapw.), *Dicellograptus divaricatus* (Hall), *Climacograptus cælatus* (Lapw.), *C. Scharenbergi* (Lapw.), an assemblage of fossils very similar in its main features to that afforded by the lowest (*Climacograptus-Wilsoni*) zone of the Hartfell division.

Few traces of this relationship, however, are exhibited by the second and southerly black band. This is similar to the foregoing in mineralogical character, but appears to be 14 or 15 feet in thickness. It yields fossils only in one small seam near its summit; these include:—

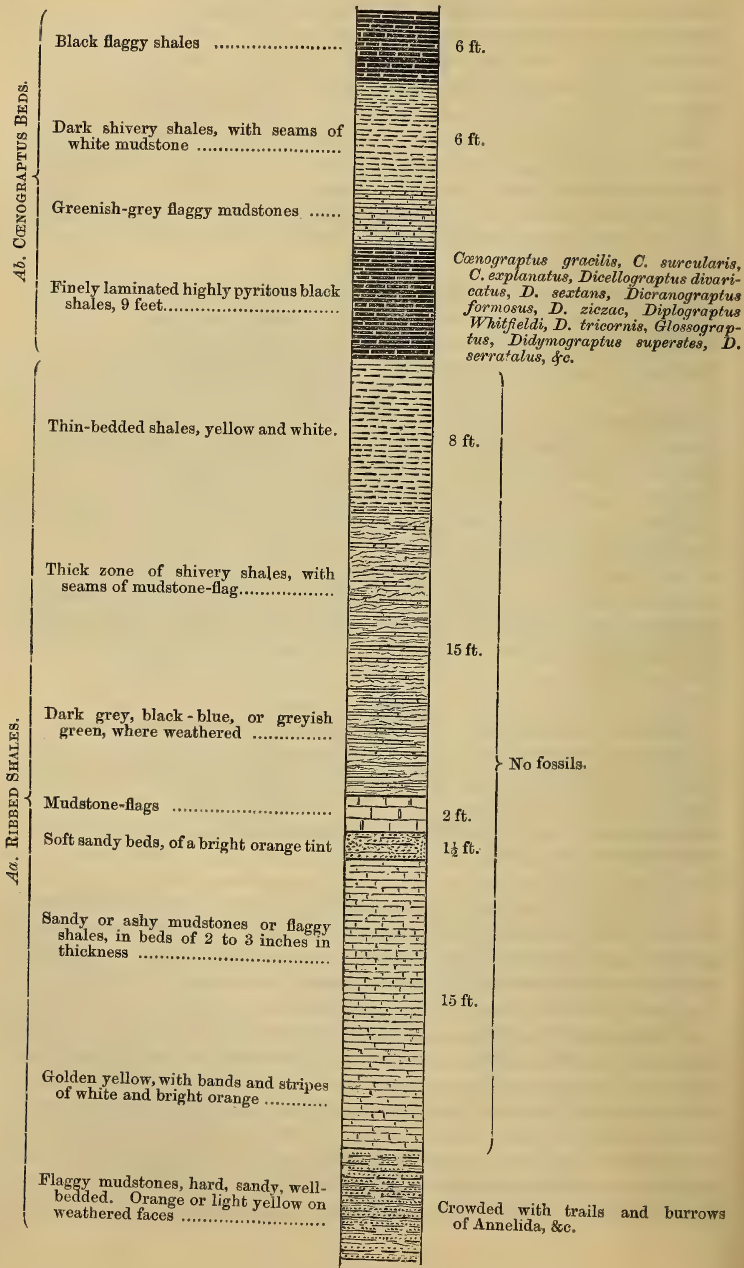
Fossils from the First Glenkiln Band of Craigmichan Scaurs.

Thamnograptus typus (*Hall*).	Climacograptus perexcavatus (*Lapw.*).
Dicellograptus Forchhammeri (*Gein.*).	—— cælatus (*Lapw.*).
Dicranograptus ziczac (*Lapw.*).	—— Scharenbergi (*Lapw.*).
Diplograptus foliaceus (*Murch.*).	Glossograptus, sp.
—— angustifolius (*Hall*).	

At *Berrybush* several distinct sections show a similar thickness of concretionary and shattered mudstones and shales, with intercalated ribs of hard sandstone, in corresponding relationship to soft pale-coloured mudstones with thick seams of black shale (fig. 26).

In the eastermost of these sections, 57 feet of these barren beds are seen, here, however, distinctly dipping *below* the dark shales at an angle of 45°. They are softer and in every way less altered than in the former locality, weathering of a pale orange-colour. It is impossible to identify the dark shales; but, as will be seen from a comparison of the sections given, there can be no doubt of the equivalency of the ribbed mudstone groups. If, however, the dark shales are actually the higher beds, the section must be inverted with respect to that of Craigmichan. In the mudstones the burrows

Fig. 26.—*Vertical Section* II. Cœnograptus *Beds &c.* (*Berrybush Burn*). (Typical Section.)



(Scale, 1 inch to 10 feet.)

and trails of Annelida are exceedingly abundant upon one horizon. The dark shales are very soft, highly pyritous, and, as a rule, finely laminated and very fossiliferous. Where weathered, they contain the following fossils :—

Fossils from the Black Bands of Berrybush Burn.

Cœnograptus gracilis (*Hall*).
—— surcularis (*Hall*).
—— explanatus (*Lapw.*).
Didymograptus superstes (*Lapw.*).
—— serratulus (*Hall*).
Dicellograptus divaricatus (*Hall*).
—— sextans (*Hall*).
—— Forchhammeri (*Gein.*).
Dicranograptus formosus (*Hopk.*).
—— ziczac (*Lapw.*).
—— Nicholsoni (*Hopk.*).
—— ramosus (*Hall*).
Diplograptus tricornis (*Carr.*).
Diplograptus foliaceus (*Murch.*).
—— angustifolius (*Hall*).
—— dentatus (*Brongn.*).
—— bimucronatus (*Nich.*).
Glossograptus Hincksi (*Hopk.*).
Clathrograptus cuneiformis (*Lapw.*).
Climacograptus bicornis (*Hall*).
—— cælatus (*Lapw.*).
—— Scharenbergi (*Lapw.*).
—— perexcavatus (*Lapw.*).
Thamnograptus typus (*Hall*).
Diplograptus Whitfieldi (*Hall*).

Many of these are in fragments, and few are in a good state of preservation. The most prolific band is so aluminiferous that it is almost impossible to preserve its fossils. In this respect it agrees precisely with the corresponding band of Douglas Burn, Belcraig, &c.

At Glenkiln the most intelligible section is that given in fig. 19, p. 286. The lowest beds of this age visible on the south side of the stream are three bands of black slaty shales, replete with badly preserved fossils, and associated with white or very light-coloured mudstones. The black beds yield, in the neighbourhood of the old coal-shaft, the following fossils :—

Fossils from the Black Shales of Black Linn.

Cœnograptus gracilis (*Hall*).
—— surcularis (*Hall*).
—— explanatus (*Lapw.*).
Didymograptus superstes (*Lapw.*).
—— serratulus (*Hall*).
Dicellograptus divaricatus (*Hall*).
—— Forchhammeri (*Geinitz*).
—— sextans (*Hall*).
Dicranograptus formosus (*Hopk.*).
—— ziczac (*Lapw.*).
—— ramosus (*Hall*).
—— Nicholsoni (*Hopk.*).
Diplograptus tricornis (*Carr.*).
—— foliaceus (*Murch.*).
—— augustifolius (*Hall*).
—— Whitfieldi (*Hall*).
—— bimucronatus (*Nich.*).
Glossograptus Hincksi (*Hopk.*).
Clathrograptus cuneiformis (*Lapw.*).
Climacograptus bicornis (*Hall*).
—— Scharenbergi (*Lapw.*).
—— cælatus (*Lapw.*).
—— perexcavatus (*Lapw.*).
Thamnograptus typus (*Hall*).

What appear to be the same beds are seen on the opposite side of the main stream, at the foot of the small burn which enters from the north. Their fossils are obtainable in abundance in the small cliffs on the right bank of the main stream, and are, many of them, admirably preserved. All those given in the forgoing list (with the exception of the *Didymograpti*) have been here collected, and, in addition, the peculiar forms of sponges found at Dobb's Linn. To the north of these black shales a long section of very light-coloured shattery mudstone is visible, apparently overlying them, but possibly of earlier date.

Between the two black-shale exposures lie the grey- and orange-coloured mudstones with ribs of flagstone, so conspicuous in the Craigmichan and Berrybush sections. They are, however, too much faulted and contorted to allow us to determine with certainty their precise relationship to the foregoing beds, or to those of the more recent Hartfell Shales.

The small sections of Glenkiln Shales visible at Belcraig have already been sufficiently described. That in the main stream shows only the dark shales ; in the side stream many of the pale mudstones are apparent (fig. 18, p. 284).

In the main cliff at Dobb's Linn, 12 feet of the fossiliferous portion of the Glenkiln Shales are exposed. Fossils are not uncommon, but are generally in a very indifferent state of preservation.

Fossils from the Glenkiln Shales of Dobb's Linn.

Dicellograptus Forchhammeri (*Gein.*).
Didymograptus superstes (*Lapw.*).
Dicranograptus ziczac (*Lapw.*).
—— Nicholsoni (*Hopk.*).
Diplograptus foliaceus (*Murch.*).
—— tricornis (*Carr.*).
Diplograptus angustifolius (*Hall*).
—— ? bimucronatus (*Nich.*).
Climacograptus bicornis (*Hall*).
—— ——, var. peltifer (*Lapw.*).
—— perexcavatus (*Lapw.*).
Thamnograptus typus (*Hall*).

Lithologically, the unfossiliferous portions of the Glenkiln Shales and the superior subgroup of barren mudstones of the overlying Hartfell division are very similar in their general features ; and it occasionally happens that when the two are seen in juxtaposition it is almost impossible to distinguish them. This is not the case, however, where the intercalated flagstone ribs are present, as these are wanting from all except the very lowest Hartfell Shales. There is a corresponding resemblance in the carbonaceous beds of the two divisions, both consisting of hard black slaty shales and thin-bedded flags.

On the other hand the zoological features of the Glenkiln Shale are strikingly distinct. Its fauna is characterized by the exclusive presence of such conspicuous genera as *Cœnograptus*, *Didymograptus*, and *Thamnograptus*, none of which have hitherto been recognized in strata of later age. Even the genera common to its lower beds and those of the Hartfell Shales are represented in the two formations by species totally distinct. The most prevalent of the peculiar Glenkiln species belonging to these common genera are *Dicellograptus divaricatus* (Hall), *D. sextans* (Hall), *Dicranograptus formosus* (Hopk.), *D. ziczac* (Lapw.), *Diplograptus Whitfieldi* (Hall), *D. dentatus* (Brongn.), *Climacograptus cœlatus* (Lapw.), &c.

§ II. *The Hartfell Shales.*

The second or Hartfell division of the Moffat Series attains a thickness of about 100 feet in the typical sections of the Moffat district. In lithological character its beds resemble those of the underlying Glenkiln division, the black shales having a corresponding plate-like or slaty structure, and the pale mudstones weathering down into similar small prismoid fragments of a deep grey or orange-yellow colour. On the other hand, the dark fossiliferous shales are more numerous, and are grouped together into a single mass, or form narrow seams of a few inches in thickness among the barren mudstones. A further distinction is shown in the absence of the peculiar ribs of hard grey siliceous flagstones so conspicuous in the underlying group.

Mineralogically the line of demarcation between the Glenkiln and Hartfell divisions is well marked, and is recognizable at a glance wherever the two groups are seen in conformable juxtaposition. The thick mass of pale flags and mudstones last described constitutes the concluding portion of the Glenkiln beds; and the base of the Hartfell division is formed by the black shales, in which fossils begin to reappear in abundance. The upper boundary-line is quite as distinct, a similar group of barren mudstones being intercalated between the fossiliferous Hartfell strata and the basal beds of the Birkhill Shales.

Palæontologically there is no actual break between the Glenkiln and Hartfell divisions. The fossils of the lower division die out one by one as we ascend the succession, and are as gradually replaced by others till the change of fauna is complete. Thus, although the two successive faunas are linked together by a large community of genera and species, yet, on the other hand, the typical beds of the two formations have scarcely a single fossil in common.

At the summit of the Hartfell Shales, on the contrary, the palæontological break is almost complete. Two Graptolites only are supposed to pass up into the overlying Birkhill formation, and even these are represented by very distinct varieties.

The fauna of the Hartfell Shales is characterized chiefly by the extraordinary predominance of the genera *Dicellograptus*, *Pleurograptus*, and *Diplograptus*. *Dicellograptus* is a survival from the Glenkiln fauna, in which, however, it plays a very insignificant part. Here, on the other hand, its individuals swarm in countless multitudes; on many horizons the surface of the shale-beds is almost hidden from sight by the complex network formed of the entangled branches of thousands of examples.

Diplograptus is common to all the divisions of the Moffat Series; but in none is it so prolific as in the Hartfell Shales, where it is fully equal to *Dicellograptus* in variety of form and abundance of individuals.

Pleurograptus, with its intimate ally, *Amphigraptus*, is strictly confined to the Hartfell division, and even within it rarely transgresses the limits of the zone to which it gives its name.

There is an extraordinary mortality among the Graptolites in this division. Not only do the peculiar types, *Pleurograptus* and *Amphigraptus*, arise, culminate, and decay within the formation itself, but *Dicellograptus*, *Dicranograptus*, *Lasiograptus*, *Glossograptus*, and

Leptograptus, survivors from the Glenkiln Shales, all become extinct before we reach its highest beds. The allied genera *Climacograptus* and *Diplograptus* are all that remain to link on the richly varied forms of the Glenkiln beds to the highly prolific but monotonous fauna of the Birkhill Shales.

(a) *Lower Hartfell.*

The Hartfell Shales fall naturally into two mineralogical subdivisions—a lower group of dark fossiliferous shales, and an upper group of pale barren mudstones.

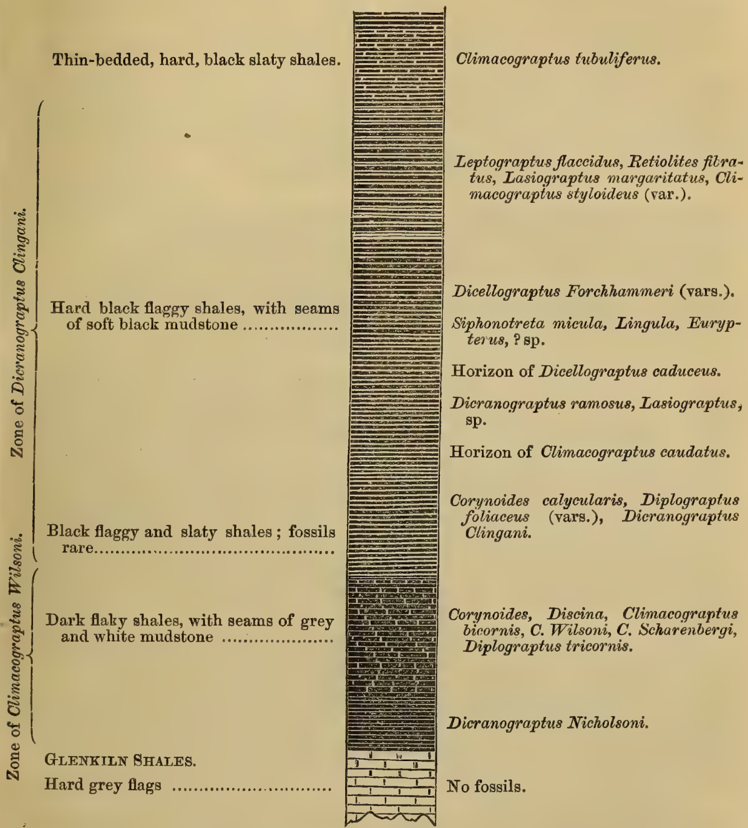
The Lower Hartfell is essentially a homogeneous mass of black carbonaceous flags and slates, more or less fossiliferous throughout. There occur, however, numerous intercalated seams of pale-coloured argillaceous matter, sometimes hard and flinty, at other times soft and easily disintegrated, and invariably destitute of all trace of organic life. The distribution of these unfossiliferous beds allows us to recognize three successive mineralogical subdivisions, which form also the three palæontological zones of *Climacograptus Wilsoni* (Lapw.), *Dicranograptus Clingani* (Carr.), and *Pleurograptus linearis* (Carr.).

i. *Zone of* Climacograptus Wilsoni *(Lapw.)* (fig. 27).—This zone attains its most perfect development and most satisfactorily exhibits its relationship to the beds above and below it in the North Cliff at Hartfell Spa. Its basal beds run in a straight line for forty or fifty yards along the steep slope immediately above the mineral spring, distinctly overlying the soft yellow mudstones of the Glenkiln, and as clearly supporting and passing up into the main mass of the Hartfell Shales. The zone forms a long projecting cornice; its strata dipping into the face of the cliff at an angle of about 40°. They are wholly free from complication by fault or curvature, and are all in such a position as to admit of a thorough investigation.

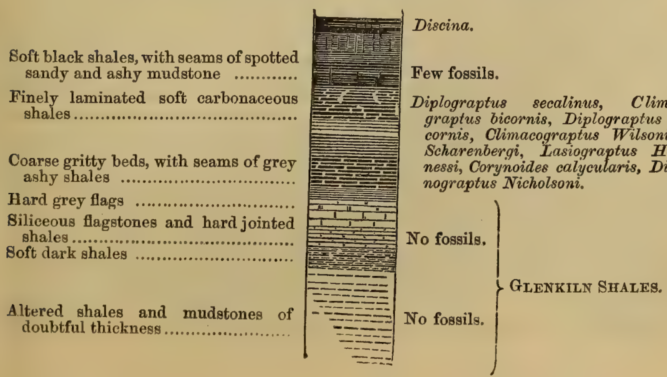
The prominent appearance of this cornice, and its freedom from the accidents which have befallen the surrounding beds, is due to the presence of a bed of siliceous flags about 11 feet in thickness, similar in all respects to those so frequently adverted to in our description of the Glenkiln Shales, of which, indeed, it is the final band. Like them it is highly resistant of atmospheric influences, but ultimately weathers into cuboidal fragments. The bed upon which it reposes is one of the dark, greyish-black flaggy shales of the Glenkiln division, which in its turn passes downwards into a great thickness of soft yellow mudstone. These three beds are all of Glenkiln age, the Hartfell Shales commencing immediately above the siliceous band.

This last is succeeded by a grey band of about a foot in thickness, which passes upwards into 2½ feet of soft black flaky mudstone shales, separating under the hammer into large flakes or irregular plates. These contain numerous narrow seams of shale of an open texture, with a coarse ashy feel, and spotted superficially with white or cream-coloured specks of foreign matter. The following 3 feet of strata show few of these coarser lines, and the laminæ are thinner

Fig. 27.—*Vertical Section* III. Lower Hartfell Shale *&c.* (*Dobb's Linn*). (*Continued upon Section* IV. p. 315).



Zone of Climacograptus Wilsoni *&c.* (*Hartfell*).



and of an intense black. These, again, support two feet of somewhat similar beds, distinguished, however, by the presence of numerous thin ribs of hard grey rock. Above follows the thick mass of black flags forming the base of the *D.-Clingani* zone.

The whole of the *C.-Wilsoni* beds are totally barren of fossils, except in a few thin seams, where the laminæ are of a coarser or more open texture than usual. These swarm with Graptolites in admirable preservation. The forms collected from this zone at Hartfell Spa are given in the following list:—

Leptograptus flaccidus (*Hall*).
Dicranograptus Nicholsoni (*Hopk.*).
—— ramosus (*Hall*).
Climacograptus Wilsoni (*Lapw.*).
—— bicornis (*Hall*).
—— ——, var. tridentatus (*Lapw.*).
—— Scharenbergi (*Lapw.*).
Diplograptus foliaceus (*Murch.*).
—— tricornis (*Carr.*).
—— truncatus (*Lapw.*).
Glossograptus Hincksi (*Hopk.*).
Lasiograptus Harknessi (*Nich.*).
Corynoides calycularis (*Nich.*).
Discina, sp.

At Dobb's Linn the band of flinty shale at the base of the zone agrees precisely in thickness and in mineralogical character with that of Hartfell Spa. It is immediately succeeded by the $2\frac{1}{2}$ feet of platy shales. Here, however, the intercalated coarser seams have no longer the spotted appearance of those of Hartfell, but are softer and more finely laminated, and make up a much larger proportion of the beds. The remainder of the zone is formed by the deep black shales, here almost destitute of the thin ribs of harder rock, but containing more of the soft grey or cream-coloured bands (fig. 27).

The fossils are restricted as before to a few of the softer and coarser laminæ. In these they are found in a state of high relief, far exceeding in beauty of preservation those collected from any of the succeeding zones. Even the grey beds yield occasionally traces of the life of the period in the shape of burrows of Annelides, skeletons and spicula of sponges, small *Orbiculæ*, and the like.

These beds have been studied more particularly than those of Hartfell; but no forms have been detected in addition to those given in the foregoing list, all of which are present in abundance.

The *C.-Wilsoni* zone forms the inferior portion of the partially inverted synclinal of Hartfell Shale visible in the Black Linn of Glenkiln Burn (fig. 19, p. 286). It is beautifully shown on the north side of the trough. It has here a thickness of about 8 feet. The dark flaky shales, though present, appear to be far less abundant than in the two former localities, and there is a simultaneous increase in the amount of grey shale and flagstones. The hard grey ribs seen at Hartfell Spa, but almost absent from the section in Dobb's Linn, are here very numerous, and give to the section generally a marked similarity to those in exposures of the Glenkiln division. The intractable bed at the base of the zone is slightly thicker than usual, and does not exhibit such clear traces of stratification.

Fossils are rare. As usual, they are in a state of half-relief.

The only forms I have collected from the zone at this locality are:—

Dicellograptus moffatensis (?) (*Carr.*).
Dicranograptus Nicholsoni (*Hopk.*).
Climacograptus Wilsoni (*Lapw.*).
Climacograptus Scharenbergi (*Lapw.*).
Diplograptus foliaceus (*Murch.*).

The same zone is exposed at the foot of Fall-Law Score, near Berrybush, at Craigmichan, and at Cramalt Score, in the valley of the Meggat Water. At Craigmichan it is too much shattered to yield fossils. In the other localities they are present, but are comparatively rare.

This zone may be looked upon as marking the age of transition between the two successive formations and life-epochs of Glenkiln and Hartfell. In lithological characteristics it partakes of the peculiarities of both formations. A similar combination is apparent in its included fauna. Every species hitherto detected within the limits of this zone is a survivor from the underlying Glenkiln Shales, while none of the strictly peculiar Hartfell forms have as yet appeared upon the scene. Nevertheless we have unequivocal evidence of the high importance of the unrepresented interval between the period in which the typical Glenkiln fauna was prevalent and that in which these transitional strata were deposited, in the complete absence from the latter of such striking genera as *Cœnograptus* (Hall), *Didymograptus* (M'Coy), *Thamnograptus* (Hall), &c. In addition to these, numerous species belonging to other genera have totally disappeared, such as *Dicranograptus formosus* (Hopk.), *D. ziczac* (Lapw.), *Diplograptus Whitfieldi* (Hall), *D. dentatus* (Brongn.), &c. Even of the forms that have survived, several have been remarkably transformed. *Dicranograptus ramosus* (Hall) has lost its fringe of lateral spines, *Climacograptus bicornis* its basal disk, while *C. cœlatus* has almost certainly been transformed into the form *C. Wilsoni*. Seven of these survivors become extinct within the limits of the zone, or outlive it for an insignificant period, namely—

Climacograptus Wilsoni (*Lapw.*).
—— Scharenbergi (*Lapw.*).
Diplograptus angustifolius (*Hall*).
—— tricornis (*Carr.*).
Glossograptus Hincksi (*Hopk.*).
—— Harknessi (*Nich.*).
Discina, sp.

ii. *Zone of* Dicranograptus Clingani (*Carr.*).—This title is given to the central and most typical mass of the Hartfell Shales. All its strata are of a deep black colour, and there is a total absence throughout of the seams of pale shale and mudstone so common in the neighbouring zones. An additional distinction is furnished by the circumstance that many of its beds are hard and flag-like, forming numerous prominent ribs among the prevailing softer strata. The latter are slaty shales, about one eighth of an inch in thickness. They can be extracted in large plates, are fine-grained, tough, and ring sharply under a blow of the hammer. There is no distinct mineralogical break between this zone and the preceding, nor is it possible to indicate exactly its superior limit. For its base an arbitrary line is chosen, where the grey ribs and pale seams of the *C.-Wilsoni* zone disappear. Above, it is conveniently limited by the horizon in which *Pleurograptus linearis* (Carr.) and its associates are first detected.

At no single locality within the limits of the Moffat district are the beds of the zone in such a condition as to admit of individual study and admeasurement. Nevertheless it is generally possible to make out the various horizons, and to arrive at a close approximation to the true thickness of the entire zone.

At Hartfell its total thickness is about 22 feet, as measured among the broken beds above the line of the *C.-Wilsoni* zone in the "cornice" in the northern slope of the gorge. In Dobb's Linn 24 feet may perhaps be assigned to it. In the greatly shattered sections in the other localities mentioned it is impossible to estimate its original thickness.

Palæontologically, the most remarkable characteristic of this zone is the fact that fossils are totally absent from many of the beds and are strictly confined to certain horizons, the strata of which do not differ in any appreciable degree from those of the barren beds. On each of these horizons there is found usually a single species or variety, its individuals lying scattered all over the face of the stratum in countless numbers and in the wildest confusion.

At Hartfell three of these horizons are especially conspicuous. The lowest is characterized by the exclusive presence of *Climacograptus caudatus*. It lies about 4 feet above the base of the zone, and recurs again and again in the numerous convolutions of the northern cliffs. The second swarms with *Dicellograptus caduceus* (Lapw.), and is found near the centre of the zone; but as it is restricted to a few inches of the succession it is less easy of recognition. The third includes several neighbouring strata near the summit of the zone. Its peculiar fossil is *Climacograptus styloideus* (Lapw.), which may be collected in abundance at several points in the North Cliff.

The foregoing are peculiar forms, wholly unknown outside the limits of the horizons they distinguish; but there are numerous additional horizons belonging to such long-lived forms as *Dicellograptus Forchhammeri* (Gein.), *D. Morrisi* (Hopk.), *Retiolites fibratus* (Lapw.), &c. &c.

The species occurring within the limits of this zone in the typical section of Hartfell include:—

Leptograptus flaccidus (*Hall*).	Climacograptus scalaris, var. styloideus (*Lapw.*).
Amphigraptus radiatus (*Lapw.*).	Diplograptus foliaceus (*Murch.*).
Dicellograptus Forchhammeri (*Gein.*).	—— truncatus (*Lapw.*).
—— moffatensis (*Carr.*).	—— tricornis (*Carr.*).
—— caduceus (*Lapw.*).	Lasiograptus margaritatus (*Lapw.*).
Dicranograptus ramosus (*Hall*).	Retiolites fibratus (*Lapw.*).
—— Nicholsoni (*Hopk.*).	Lingula, sp.
—— Clingani (*Carr.*).	Corynoides calycularis (*Nich.*).
Climacograptus bicornis (*Hall*).	—— curtus (*Lapw.*).
—— scalaris (*His.*).	Eurypterus, sp.
—— ——, var. caudatus (*Lapw.*).	

In Dobb's Linn the strata of the *D.-Clingani* zone visibly overlie the streaked beds of the *Climacograptus-Wilsoni* zone in the southern angle of the Main Cliff, but they are too much broken and metamorphosed to yield many fossils. The seam with *Climacograptus caudatus* occurs in one of the small scaurs at the bottom of the cliff near its centre, but is much more satisfactorily exposed in the prolongation of the zone up the slope forming the angle between the Long Burn and that descending from the falls. Some distance above it occurs the well-marked seam with *Dicellograptus caduceus,* swarming with its characteristic fossils, and traceable southward at intervals in the Main Cliff, and northward over the summit of the North Cliff, and thence through both the projecting bosses of hard black flagstones in the slope beyond.

All the fossils given in the list from Hartfell have been detected in this zone in Dobb's Linn, together with the additional species :—

Siphonotreta micula (*M'Coy*).
Acrotreta Nicholsoni (*Dav.*).
Lingula, sp.
Eurypterus, sp.

In Glenkiln Burn a portion of this zone occupies the centre of the synclinal of the Black Linn. The seam with *Climacograptus styloideus* is easily detected on the north side of the trough, and, higher up, the horizon of *Dicellograptus caduceus.* The prevalent fossils appear to be :—

Leptograptus flaccidus (*Hall*).
Amphigraptus radiatus (*Lapw.*).
Dicellograptus moffatensis (*Carr.*).
—— Forchhammeri (*Gein.*).
Dicranograptus ramosus (*Hall*).
—— Clingani (*Carr.*).
Climacograptus caudatus (*Lapw.*), var.
—— bicornis (*Hall*).
Diplograptus foliaceus (*Murch.*).
Corynoides calycularis (*Nich.*).
—— curtus (*Lapw.*).

Many of the same fossils are found in corresponding positions in the zone as exposed at Mount Benger, Syart Score, Fall-Law Score, Moory Syke, and Craigmichan. The last three localities also exhibit its physical relationships to the zones above and below.

iii. *Zone of* Pleurograptus linearis (*Carr.*).—The hard flaggy beds of the *D.-Clingani* zone pass up everywhere by insensible gradations into an overlying group of dark thin-bedded shales. In the lower portions of this new group the shales split easily into thin slate-like sheets, similar to those of the minority of the underlying beds. Higher up they become thicker, softer, and tougher, while among them appear thin seams and bands of barren shale, white or more generally cream-coloured. These increase in number and importance as we ascend, till, finally, they occupy the whole succession, and pass insensibly into the great mass of barren mudstone of the Upper Hartfell Group. Side by side with this change in the lithological character of the strata, there takes place a corresponding alteration in the aspect of their included fossils. In the lowest bands they are mere pyritous stains upon the surface of the laminæ; in the highest they are frequently preserved in the round.

The fossiliferous portion of the zone is best studied at Mount Benger (fig. 16), where two longitudinal faults have isolated the great majority of the beds of the zone, preserved them from alteration or disturbance, and placed them in such a position that every bed admits of thorough examination. The white bands are here strictly confined to the higher half of the section, the beds of the lower subdivision agreeing in all essential respects with those of the underlying zone. The fossils are given in the following list:—

Leptograptus flaccidus (*Hall*).
—— capillaris (*Carr.*).
Amphigraptus divergens (*Hall*).
Pleurograptus linearis (*Carr.*).
Dicellograptus elegans (*Carr.*).
—— Morrisi (*Hopk.*).
Dicellograptus pumilus (*Lapw.*).
Climacograptus tubuliferus (*Lapw.*).
Diplograptus foliaceus (*Murch.*).
—— quadrimucronatus (*Hall*).
Retiolites fibratus (*Lapw.*).
Lingula, sp.

Climacograptus tubuliferus is restricted to the lowest portion of the zone as here exposed, which is also distinguished further by the exclusive presence of *Dicellograptus elegans* (Carr.).

In Dobb's Linn the strata of this zone may be followed almost continuously from the southern boundary of the Main Cliff to a point at the head of the Middle Score. The central bands, with *Pleurograptus linearis*, are entire, and yield well-preserved fossils where they are exposed in the Main Cliff; and all the species occurring in the beds at Mount Benger have been collected above the Middle Score.

At Hartfell the beds of this zone are exposed, and are highly fossiliferous at several points in the north slope. Above the "cornice," the central beds, here cut off from the succeeding strata by a small fault, are filled with excellent examples of *Pleurograptus linearis* and its associates. The higher beds, with their included white and cream-coloured seams, occur again and again in the numerous scores that furrow the slope beyond.

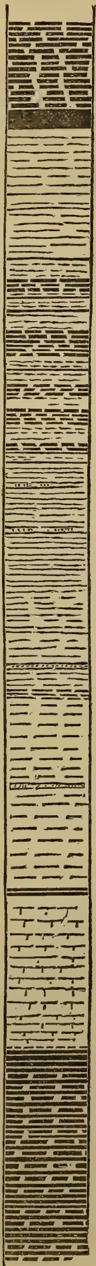
These pale-coloured bands become very numerous in the bands above St. Mary's Loch. At Fall-Law Score, Yellow Mire, &c. they appear to have coalesced into a thick bed of soft white mudstone. In the sections of the Moory Syke, Craigmichan, and Belcraig, the underlying fossiliferous bands are more prominently exhibited, and yield occasionally, when less altered than usual, a few of their characteristic Graptolites.

Everywhere this well-marked zone is characterized by the exclusive presence of the peculiar compound genus *Pleurograptus*, which has never yet been detected in any of the fossiliferous strata above or below. Here also do we find for the last time the genera *Leptograptus*, *Amphigraptus*, and *Dicranograptus*, and several species belonging to other genera—*Diplograptus foliaceus* (Murch.), *Dicellograptus Morrisi* (Hopk.), *D. elegans* (Carr.), *Climacograptus tubuliferus*, &c.

(b) *Upper Hartfell.*

The peculiar white or grey seams so prevalent in the upper portion of the preceding zone finally exclude all trace of the asso-

Fig. 28.—*Vertical Section* IV. Upper Hartfell Shale (*Dobb's Linn*).



	Shivery shale, black and grey............	*Diplograptus acuminatus.*
	Basal seam of Birkhill Shale, drab-coloured tough shale......................	Crowded with *Climacograptus* in half-relief.
*Bb*². *Zone of* Dicellograptus anceps.	Green shales and mudstone	No fossils.
	Seam of soft black shale, pyritous shivery shales, yellow and grey ...	*Diplograptus truncatus.* *Climacograptus bicornis* (*tuberculatus*).
	Seam of soft black carbonaceous shale.	*Dicellograptus anceps.* Crowded with *Diplogr. truncatus.*
	Yellow and green shivery shales	
	Seams of soft black flaky shale, with partings of white and yellow sandy muds, shales, and clays	*Dicellograptus anceps.* *Diplogr. truncatus*, &c.
*Bb*¹. "Barren Mudstone."	Thin-bedded light green shivery shales, with a few hard seams of flagstone, slightly calcareous	No fossils.
	Thick-bedded light green mudstones ...	
	Seam of black carbonaceous shale, 2 inches in thickness	*Diplograptus, Climacograptus, Dicellograptus.*
	Dark grey mudstones, some almost black, with yellow or orange-coloured surface	
*Ba*³. *Zone of* Pleurograptus linearis.	Soft black flags and shales, with partings of white clay	*Diplograptus foliaceus.* *Pleurograptus linearis, Diplograptus quadrimucronatus.* *Dictyonema moffatensis.*
	Hard slaty shales, black, thin-bedded.	*Pleurograptus linearis, Amphigraptus*, sp., *Diplograptus foliaceus.*

(Continued from Vertical Section III.)

ciated black fossiliferous shales, and lead insensibly into the thick overlying mass of pale mudstones constituting the Upper Hartfell Group. As a whole the beds of the group are totally barren of fossils, which are met with only along two widely separated horizons. Here, however, they occur in abundance, and the facies of the fauna thus indicated compels us to assign the containing beds to the same general division as the underlying mass of dark shales.

The most intelligible section of the beds of this subdivision is exhibited in the Main Cliff at Dobb's Linn and in the gully below the falls (fig. 28).

i. *Barren Mudstones.*—The inferior portion of the Upper Hartfell consists here of about 30 feet of light-coloured shales and mudstones. In the lower half of the zone they are arranged in beds of from 6 inches to a foot in thickness; above they form a homogeneous mass of shaly rock with few traces of stratification. The inferior beds weather into slabs of a deep rusty-brown colour; the higher beds into flakes or angular splinters of a light yellow tint.

No fossils are present in any of its beds, except in a thin seam of black shale, about 2 inches in thickness, not far removed from the base of the zone. This swarms with poorly preserved Graptolites, chiefly *Dicellograptus Forchhammeri* (Geinitz), *Climacograptus scalaris*? (His.), *Diplograptus truncatus* (Lapw.).

The same fossiliferous seam can be recognized in the section at the Moory Syke (fig. 9); and there is even a trace of it in the magnificent section of Craigmichan Scaurs.

Intercalated among these "Barren Mudstones" occur several thin courses or ribs of hard compact rock, slightly calcareous, weathering exteriorly of a deep drab or dark brown colour. They have been recognized only in the section at Dobb's Linn.

At Craigmichan the lower and thick-bedded portion is very conspicuous, and the whole zone has expanded to a total thickness of 50 feet; but this may include the representative of the succeeding zone, which is not individually recognizable in the section at that locality.

Nowhere are the Barren Mudstones so conspicuously exhibited as in Belcraig Burn, where they occupy the greater part of the exposure, and display their peculiar characteristics to perfection.

These beds also occur along the Ettrick River at Berrybush and at Hartfell Spa, everywhere under the same general aspect, and everywhere totally barren of fossils.

ii. *Zone of* Dicellograptus anceps (*Nich.*).—At Dobb's Linn the thick mass of the "Barren Mudstones" is surmounted by a thinner group of somewhat similar beds, diversified by seams of black fossiliferous shales and variegated mudstones. The higher division of this overlying group is formed of 6 feet of greenish-grey flaggy shale, nonfossiliferous, and identical in all respects with the typical beds of the "Barren Mudstone." The lower division, which is also about 6 feet in thickness, contains five or six thin seams of carbonaceous shale, soft, fossiliferous, and interbedded with numerous lines of grey, yellow, or white mudstone, never more than 2 or 3 inches in thickness.

The arrangement of the strata of this well-marked zone has been given already in our description of the physical structure of the ground at Dobb's Linn. (p. 253). The fossils obtained belong exclusively to the species:—

Climacograptus bicornis, var. tuberculatus, *Nich.*	Diplograptus truncatus (*Lapw.*).
—— scalaris (*His.*).	Dicellograptus anceps (*Nich.*).

The same zone is exposed in Riskinhope Burn (fig. 10) under the same general aspect, and yielding the foregoing Graptolites in some abundance; but it is more satisfactorily exhibited in the beautiful section in Black Grain (fig. 12), where the dark seams are very prominent, and the fossils are numerous and well preserved.

§ III. *Birkhill Shales.*

The third or Birkhill division of the Moffat Series comprises all the fossiliferous strata that intervene between the *D.-anceps* zone of the Upper Hartfell Shales and the coarse grits and flagstones of the Gala group. In the typical section of Dobb's Linn, the total thickness of the division is about 140 feet. This thickness is probably exceeded in the district lying to the south of the Moffat valley; but in none of the sections there exhibited are its strata in such an attitude as to admit of exact admeasurement.

In their mineralogical characters the beds of this division, while bearing a decided resemblance to those of the other divisions of the Moffat Series, at the same time possess many marked peculiarities. The dark carbonaceous shales of this division never show the slaty, close-grained texture or the plate-like structure of those of the subjacent Hartfell group. They are normally soft, irregularly laminated, and split under the hammer into small slabs or flakes, with a ridged and uneven surface. The unfossiliferous mudstones are quite as distinct, no longer weathering down into yellow prismoid fragments, but forming thin flag-like sheets of a greyish-green or deep purple colour, and resembling in all their essential features those of the corresponding strata of the succeeding Gala group.

The physical peculiarities of the rocks of the Birkhill division are accompanied by far more important distinctions in the facies of its included fauna. Of the numerous genera of compound Graptoloidea which gave such a varied character to the fauna of the Glenkiln Shales, and many of which have accompanied us in our upward progress into the typical beds of the Hartfell division, not one passes up into the Birkhill Shales. Here, on the other hand, the extraordinary prevalence of Monograptidæ upon every zone is in striking contrast to what occurs in the inferior division, where not the slightest trace of any form of this family has ever been detected.

The two genera *Monograptus* and *Rastrites* swarm abundantly in all except the lowest zone of the Birkhill Shales, and with the more sparingly distributed genera *Diplograptus*, *Climacograptus*, and *Retiolites* (together with a few scattered forms of Crustacea and Spongidæ) constitute the whole of the fossils of the group. Consequently, while there is no falling off in respect of individuals or even species (many of the beds bearing favourable comparison with the most prolific "horizons" of the Hartfell Shales), yet, when contrasted with that afforded by the preceding divisions, the fauna of the Birkhill Shales is strangely monotonous throughout. No better proof could perhaps be adduced of our having clearly overstepped the limits of the great Llandeilo-Bala formation, where the Graptolithina attain their maximum, and that we are now almost on the threshold of those Upper Silurian rocks where these strange old creatures disappear from our sight for ever.

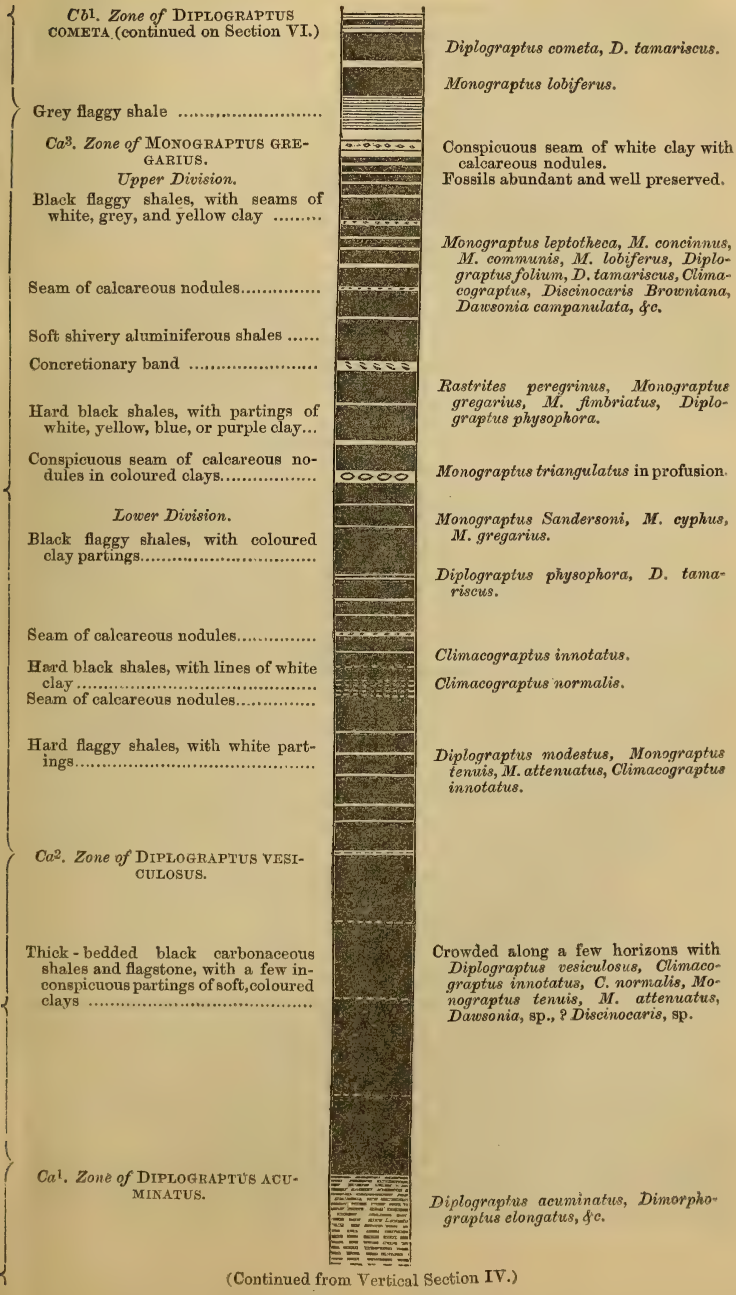
It will be superfluous to enumerate all the localities where this division is exposed. This has been done already to a large extent in the stratigraphical portion of the paper. As it immediately underlies the greywackes, some of the zones of the group are necessarily exposed in every spot where the Moffat Shales are visible, the extent of our acquaintance with its strata and fossils increasing in direct proportion as we approach its highest limit. It will be sufficient for our purpose to define the characters of its successive zones in some of the more symmetrical and fossiliferous sections, and, at the same time, to indicate a few of the additional sections where these facts may be verified and supplemented.

(a) *Lower Birkhill.* (Fig. 29.)

The thickness of this subdivision in the typical section of the Main Cliff is about 60 feet. It is made up almost wholly of black carbonaceous shales, occasionally diversified by intercalated seams of variegated mudstones. The *general* lithological and palæontological features of the subdivision have been already so frequently dwelt upon, that it is only necessary in this place to give a brief summary of the characteristics of its three component zones.

i. *Zone of* Diplograptus acuminatus (*Nich.*).—At the base of the inferior subdivision of the Birkhill Shales lies a mass of shivery shales, black- or blue-hearted, and weathering down into thin flakes, superficially of a bright yellow colour. The basal seam of this band is about 6 inches in thickness, consisting of a tough, flag-like shale, slightly calcareous (see fig. 28). It is of a deep drab or gingerbread colour where it is affected by the weather, and it yields numerous fossils in admirable preservation. The details of the various sections of this zone in Dobb's Linn may be gathered from our description of the rocks of that locality. Its commonest fossils are *Diplograptus acuminatus* (Nich.), *D. vesiculosus* (Nich.), rare, *Climacograptus scalaris* (His.), *Dimorphograptus elongatus* (Lapw.). The same physical characters mark this zone at Thirlstane Score, Scabcleuch, and Belcraig. At the last-named locality it affords the same fossils. In the broken section at Hartfell *Diplograptus acuminatus* occurs in some abund-

Fig. 29.—*Vertical Section* V. Lower Birkhill Shale (*Dobb's Linn*).



ance; but neither there nor in the great section at Craigmichan Scaurs can the zone be identified with certainty.

ii. *Zone of* Diplograptus vesiculosus (*Nich.*).—This zone with its hard thick-bedded black flagstones, everywhere so prominent among the surrounding strata and so doggedly resistant of those atmospheric influences that have crumbled the underlying shales to powder, has been so frequently alluded to in the foregoing pages as to preclude any special description in this place. Next to the typical section at Dobb's Linn it is exposed in the Score above Thirlstane Burn, and in the fine section at Belcraig. Strictly speaking, it everywhere merges imperceptibly into the lowest beds of the succeeding zone, which possess corresponding lithological characters and yield, generally speaking, the same fossils.

The fauna of the *D.-vesiculosus* zone at Dobb's Linn includes the following species, which occur in abundance on a few distant horizons, the intervening beds being wholly destitute of organic remains:—*Diplograptus vesiculosus* (Nich.), *Climacograptus scalaris* (His.), *C. innotatus* (Nich.), *Monograptus tenuis* (Portl.), *M. attenuatus* (Hopk.), *Dimorphograptus elongatus* (Lapw.).

iii. *Zone of* Monograptus gregarius (*Lapw.*).—The flags of the *D.-vesiculosus* zone graduate upwards into a great succession of black flags, shales, and mudstones. Among them abound seams and beds of coloured clay or mudstone, blue, grey, purple, or black. These are much softer than the flaggy rock, and are worn down into deep grooves and channels on the face of every section. At intervals occur bands and lines of nodules of calcareous ironstone, forming prominent ribs and ridges, rising conspicuously amid the more tractable beds around. The whole group abounds with iron pyrites, either included in the shales themselves, or forming seams and bunches of bright yellow concretions and crystals. The waters that trickle over these beds take up this mineral in their course, streaking and staining the whole mass of beds of a deep rusty yellow with a subsequent deposit of oxide of iron.

At Dobb's Linn a bed of concretionary and calcareous ironstone, near the centre of the zone, forms a convenient boundary between its lower and upper divisions. Below that line the dark carbonaceous shales are hard and flag-like, and show few of the coloured courses. Above it the beds are thinner, and the mudstone bands are excessively numerous. The lower division is here 20 feet in thickness, and the lower 15 feet. This thickness is greatly in excess of that of any of the remaining zones of the Birkhill Shales; and it will also be seen that the fauna is larger and more varied. There can be no doubt, however, that these beds constitute one single physical mass, which, neither mineralogically nor zoologically, is it possible satisfactorily to subdivide.

This group stands related to the main mass of the Birkhill formation in a corresponding position to that occupied by the zone of *Dicellograptus Clingani* with respect to the Hartfell Shales. It embraces, namely, a large proportion of the most distinctive beds of the formation and includes a majority of its most characteristic fossils.

Below the central nodule-band the commonest species are :—

Rastrites peregrinus (*Barr.*).
Monograptus Sandersoni (*Lapw.*).
—— cyphus (*Lapw.*).
—— tenuis (*Portl.*).
—— communis (*Lapw.*).
—— triangulatus (*Harkn.*).
—— gregarius (*Lapw.*).
Monograptus concinnus (*Lapw.*).
Diplograptus tamariscus (*Nich.*).
—— vesiculosus (*Nich.*).
—— physophora (*Nich.*).
—— modestus (*Lapw.*).
Climacograptus innotatus (*Nich.*).

Above the nodule-band many of these recur and are associated with :—

Monograptus leptotheca (*Lapw.*).
—— lobiferus (*M'Coy*).
Dawsonia campanulata (*Nich.*).
Discinocaris Browniana (*Woodw.*).
Diplograptus folium (*His.*).
—— insectiformis (*Nich.*).

Some of these forms have a very restricted vertical range in the beds of this zone. *Monograptus Sandersoni* (Lapw.) and *M. fimbriatus* (Nich.) are unknown above the central line. *Monograptus triangulatus* (Harkn.) occurs only in the neighbourhood of the nodule-band. Neither *Rastrites peregrinus* nor *Diplograptus vesiculosus* reach the summit of the group.

All the localities noted as exhibiting the black and variegated beds of this zone afford also, as a rule, their characteristic fossils. Nowhere is it possible to point out any marked distinction between these beds at Dobb's Linn and their representatives elsewhere, except, perhaps, along the southern band of Ettrick and Glenkiln, where they are usually greatly hardened, have a somewhat slaty structure, and show only a small proportion of the variegated mudstones.

In the last three or four feet of the beds of this zone, as exposed at Birkhill and in the Thirlstane Score, we have evidence of the commencement of those conditions which led to the production of the thick overlying mass of grey flags, in the presence of numerous hard seams of grey shale intercalated among the normal fossiliferous dark shales and mudstones. The terminal beds afford always the best-preserved fossils of the zone, but they are rare and of few species.

(b) *Upper Birkhill.* (Fig. 30.)

The finest and, in many respects, the most typical section of this subdivision is seen in the gorge and corrie immediately below the falls of Dobb's Linn. It here embraces about 77 feet of barren grey flaggy mudstones, and includes three distinct groups or horizons of black fossiliferous shales. The base of the group appears well-defined, being marked by a sudden lithological break. Actually, however, its first fossiliferous zone has little to distinguish it from the underlying beds. The grey shales near the summit of the group become harder and more flag-like as we ascend the succession, and there is an almost insensible lithological transition into the basement beds of the great greywacke formation of the Gala group. From the circumstances of the case, the final line of demarcation is neces-

Fig. 30.—*Vertical Section* VI. UPPER BIRKHILL SHALE (*Dobb's Linn*).

Flagstones and greywackes of the Gala group	
*Cb*3. *Zone of* RASTRITES MAXIMUS.	
Grey flaggy shales, 15 ft. (curtailed)...	No fossils.
Grey flags	
Soft black-shale seam, weathering yellow-edged	
Grey flaggy shale	3 ft.
Seam of hard flaggy black shale	*Rastrites maximus, Monograptus Halli.*
White-clay seam	1 ft.
Soft black pyritous shale, concretionary	*Rastrites maximus, M. Halli, M. spinigerus, M. Hisingeri, Diplograptus Hughesi,* &c. in partial relief.
White clay, with calcareous nodules...	
Grey flaggy shales, seams of white clay with concretions, and scattered lines of dark carbonaceous and pyritous mudstone	Few fossils.
Thin line of hard black slaty shale ...	
*Cb*2. *Zone of* MONOGRAPTUS SPINIGERUS.	
Soft sandy shales, with rough or reticulated surface	
Hard black shale	*Monograptus spinigerus, M. Hisingeri, M. intermedius.*
Soft sandy pale shale	
Hard flaggy black shale, with cuboidal fracture	*Monograptus tenuis, Diplograptus Hughesi.*
Bed of soft highly pyritous black shale	Crowded with *Monograptus spinigerus, Monograptus Hisingeri,* &c.
Hard bands of black shale, parted by lines of white clay	
Rusty brown shivery or splintery shales	*Monograptus spinigerus, M. Hisingeri, M. tenuis, Diplograptus sinuatus, D. tamariscus, D. folium,* &c.
Soft slaty shales, with greyish-brown or indigo-coloured surface	
	Seam covered with trails of Annelides &c.
Band of black shale	
White clay, with nodules	Fossils numerous and well preserved: *Monograptus Clingani, M. crenularis, Rastrites hybridus, Diplograptus sinuatus.*
Black shale	
Grey shales, with seams of white clay.	
*Cb*1. *Zone of* DIPLOGRAPTUS COMETA.	
Soft flaky aluminiferous black shales...	*Diplograptus cometa, D. tamariscus, Monograptus lobiferus, M. cyphus,* &c.
Conspicuous seam of white clay (concretions)	

(Continued from Vertical Section V.)

sarily an arbitrary one. It is drawn at the point where the first bed of greywacke is seen in the section.

Our attention has been already directed to the peculiar seams of white clay which form so striking a feature in the section of the beds of this subdivision in the locality under description. They are nowhere so remarkably conspicuous as at this spot, but they are never wholly absent in any single exposure throughout the whole of the southern portion of the Moffat district.

It is clear from a comparison of the numerous sections of these beds that the black bands increase in thickness and importance in proportion as we pass across the district to the southward. To the north they rapidly thin out, disappearing wholly in the sections along the bands of Hartfell, Headshaw, Douglas, and Meggat. There the grey beds form a single mass of barren rock, unrelieved by any intercalated fossiliferous seam whatsoever. In this direction they change gradually into a sheet of thin-bedded flagstone differing in no way from similar beds clearly interbedded with the typical greywackes of the Gala group.

Hence it is highly probable that the line marking the summit of the Moffat Series is actually drawn along slightly different horizons in the different sections. Within the limits of the present district, however, the error can be but slight, and its effect upon our conclusions of no great moment.

i. *Zone of* Diplograptus cometa.—This name is given to the first eight feet of the Upper Birkhill Shales of Dobb's Linn. The lower portion of the zone is formed of four feet of barren grey flagstone (see fig. 29); the upper portion of a similar thickness of soft black shales, weathering down into shivery fragments coated with the oxide of iron. Lithologically the zone appertains to the Grey-Shale group; palæontologically its affinities are with the underlying Black-Shale series. Its fossils are poorly preserved at this locality. The only forms collected by myself are:—

Rastrites capillaris (*Carr.*).
Monograptus lobiferus (*M'Coy*).
—— leptotheca (*Lapw.*).
—— cyphus (*Lapw.*).
—— tenuis (*Portl.*).
—— Hisingeri (*Carr.*).
Diplograptus cometa (*Gein.*).
Diplograptus tamariscus (*Carr.*).
—— sinuatus (*Nich.*).
—— folium (*His.*).
—— Hughesi (*Nich.*).
Climacograptus scalaris (*His.*), var. normalis (*Lapw.*).

The same bed appears to be exposed at Craigierig, Back Burn, in the sections in the lower portion of Selcoth Burn below Craigmichan Scaurs, &c. Beyond its value as a well-defined mineralogical horizon in the section at Dobb's Linn, the zone is of very insignificant importance in the Birkhill division.

ii. *Zone of* Monograptus spinigerus (*Nich.*).—Whatever misgivings may be felt as to the propriety of erecting the *D.-cometa* band into a distinct zone, not a moment's doubt can be entertained of the great importance of the group of strata which immediately succeeds it. Not only is its distinctness evident from the presence of several species of Graptolithina unknown in the earlier zones, but the marked mineralogical characteristics of several of its component beds and their remarkable persistence throughout the district compel us to assign it a special title.

In the "corrie" at Dobb's Linn the section of the group under consideration, though unfortunately somewhat dislocated, clearly shows a lower division of 15 feet of barren grey rock, and an upper division of 10 feet of black shales and white mudstones.

In the very centre of the lower division of barren grey shales occurs a double seam of black shale crowded with well-marked fossils, principally:—

Rastrites hybridus (*Lapw.*).	Diplograptus folium (*His.*).
Monograptus Clingani (*Carr.*).	—— tamariscus (*Nich.*).
—— runcinatus (*Lapw.*).	—— Hughesi (*Nich.*).
—— leptotheca (*Lapw.*).	Climacograptus scalaris (*His.*).

Monograptus Sedgwicki (*Portl.*) = spinigerus (*Nich.*).

The total thickness of the dark seams on this horizon is about six inches. In the beds immediately in contact with them we meet with laminæ reticulated with the trails of Annelides, and dotted with peculiar rounded protuberances.

The upper division of the zone includes at least six distinct seams of black shale. Some of these are hard and weather into irregular cuboidal pieces. Others are soft, pyritous, and yield beautifully preserved Graptolites. These black flags are divided from each other by thin seams of white mudstone or pale sandy shales. The latter are in several respects the most characteristic strata in the zone. Here they are too greatly shattered and weathered to allow us properly to appreciate their distinctive peculiarities. Elsewhere, however, they are seen to be of a light cream-colour, of a sandy texture, and with a rough harsh surface. Occasionally the latter is cut up into small lozenge-shaped patches by hundreds of fine straight grooves, rarely empty, but almost invariably filled up by quartz or pyrites.

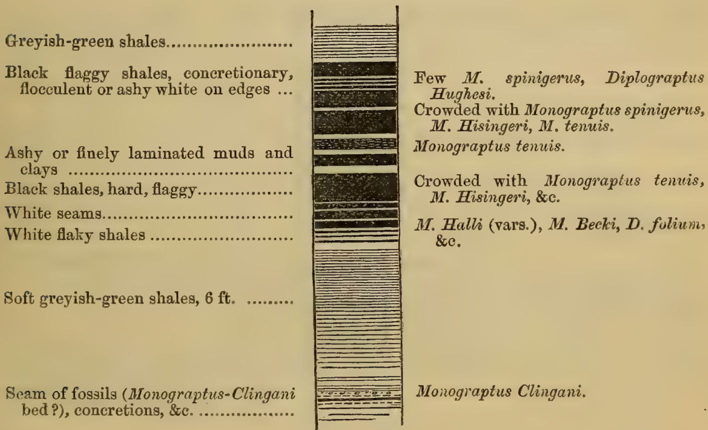
The fauna of these black shales already recognized by myself at this locality includes the following forms:—

Rastrites hybridus (*Lapw.*).	Diplograptus sinuatus (*Nich.*).
Monograptus proteus (*Barr.*).	—— tamariscus (*Nich.*).
—— spinigerus (*Nich.*).	Retiolites perlatus (*Nich.*).
—— Hisingeri (*Carr.*).	Diplograptus Hughesi (*Nich.*).
—— attenuatus (*Hopk.*).	Dawsonia, sp.
—— intermedius (*Carr.*).	Discinocaris Browniana (*Woodw.*).
—— Becki (*Barr.*).	Peltocaris aptychoides (*Salt.*).
Diplograptus folium (*His.*).	Ceratiocaris, sp. ind.

In the fine section of this zone at the Moory Syke (fig. 9, p. 270), the pale sandy beds are more perfectly exhibited than in the Dobb's Linn corrie, and there is also a more satisfactory exposure of the dark shale with *Monograptus spinigerus*, beautiful specimens of which occur in abundance. The peculiar double black seam of the lower division of the zone also occurs in a corresponding position at Thirlstane Burn, retaining fully its mineralogical characteristics and its distinctive fossils.

The best section of the beds of the *M.-spinigerus* zone is that of Eldinhope Burn in the valley of the Yarrow, where every seam is capable of exact admeasurement. It will be seen from the accompanying diagram how perfectly the beds at this spot agree with the preceding description. The double seam with *Monograptus Clingani* (Carr.) forms the base of the section, and the overlying beds of barren shales are more than a foot thicker than at Dobb's Linn (fig. 31).

Fig. 31.—*Zone of* MONOGRAPTUS SPINIGERUS (Nich.). (*Eldinhope Burn.*)



Beds belonging to this zone are visible also in Thirlstane Score (fig. 8, p. 269), Riskinhope, Muckra, Duffkinnel, &c. Everywhere they yield fossils of the list given above and none other. Everywhere, from Sundhope to Glenkiln, the seam of soft pyritous mudstone affording the spinose variety of *M. spinigerus* is the most prolific stratum, swarming with innumerable Graptolites in admirable conservation.

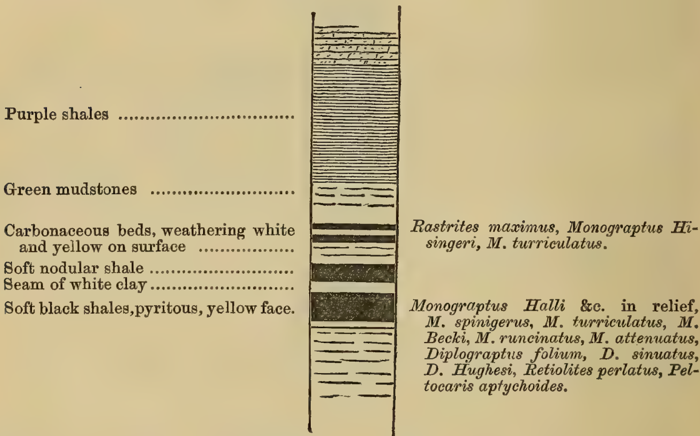
iii. *Zone of* Rastrites maximus (*Carr.*).—The concluding zone of the Moffat Series embraces the final 25 feet of shaly strata seen in the typical exposure at Dobb's Linn. Its fossils are restricted to what may conveniently be termed two pairs of black beds, separated by three feet of barren shale. The lowest bed is nearly two feet in thickness, the second about a foot, the third a few inches, and the fourth a mere line. The zone contains many of the white-clay bands, and the strata immediately in contact with the fossil beds weather of a bright yellow colour.

The fossils are generally in a state of low relief, and include :—

Rastrites maximus (*Carr.*).
Monograptus Halli (*Barr.*).
—— turriculatus (*Barr.*).
—— proteus (*Barr.*).
—— runcinatus (*Lapw.*).
—— intermedius (*Carr.*).
—— Becki (*Barr.*).
Monograptus spinigerus (*Nich.*).
—— Hisingeri (*Carr.*).
—— attenuatus (*Hopk.*).
Diplograptus folium (*His.*).
—— Hughesi (*Nich.*).
Retiolites perlatus (*Nich.*).

In Thirlstane Burn (fig. 32) the six feet of grey shale overlying the highest pair of black beds has increased to eight feet, and changed to a deep purple colour. Both pairs of black seams are here recognizable of the same relative thickness as at Dobb's Linn. The intervening three feet of green shale has, however, dwindled down to one foot. Every fossil given in the foregoing list occurs here, and in addition some peculiar sponges.

Fig. 32.—*Zone of* Rastrites maximus (*Carr.*). (*Thirlstane Score.*)



At Mount Benger the two pairs of black beds are separated by six feet of barren shale, and the fossiliferous seams are not individually recognizable. Their fossils, however, are easily obtained in abundance.

In Craigmichan only the highest pair of black beds is visible, and the barren mudstones which separate it from the greywackes have again decreased to their original six feet of thickness. The few fossils obtained here are preserved in relief in carbonate of copper, and the barren shales are stained of a deep purple hue.

The only fossils collected here are :—

Rastrites maximus (*Carr.*).
Monograptus spinigerus (*Nich.*).
—— Halli (*Barr.*).
Monograptus runcinatus (*Lapw.*).
Diplograptus folium (*His.*).

In the beautiful section at Belcraig Burn four feet only of grey shale intervene between the highest black bed of the zone and the first of the greywackes. The two pairs of fossiliferous seams split up into several subordinate beds, and are separated only by a bed of barren shale a foot in thickness. The fossils are of similar species to those cited from Craigmichan, but there occur in addition :—

Monograptus turriculatus (*Barr.*).	Monograptus Hisingeri (*Carr.*).
—— proteus (*Barr.*).	Retiolites perlatus (*Nich.*).
—— Becki (*Barr.*).	Peltocaris aptychoides (*Salt.*).

In the highest exposure at Glenkiln the *Rastrites-maximus* zone may be recognized at the base of a cliff of purple flagstone overhanging the stream. Its beds are exposed in a conspicuous rocky projection washed by the waters of the burn.

The highest seam of black shale is here divided from the first flaggy greywacke of the cliff by two feet only of non-fossiliferous purple mudstone. The upper pair of black beds are represented by a foot and a half of soft aluminiferous black shale, containing a few fragmentary Graptolites. The lower pair are represented by a bed of dark flaggy shale twice as thick as the former, and separated from it by two and half feet of barren mudstone.

The fossils of this lower bed collected by myself include *Rastrites maximus* (Carr.), *Monograptus spinigerus* (var.), *M. Halli* (Barr.), *M. runcinatus* (Lapw.).

There are several additional exposures of the *R. maximus* zone to the south of the line of the Moffat valley. The most important of these are the sections of Crosscleuch, Muckra, Whitehope, Black Grain, and Entertrona.

To the north of the Moffat valley, if we except the doubtful beds at the summit of the Moffat Shales of Garple Burn, the zone is not recognizable.

In the annexed Table the letters used bear the following signification :—

c. Commmon.
C. Very common
r. Rare.
V. Very rare.

Table showing the Vertical Distribution of the Fossils of the Moffat Series.

List of Species.	GLENKILN.	HARTFELL.					BIRKHILL.						Foreign localities.
		LOWER.			UPPER.		LOWER.			UPPER.			
		Zone of *Clim. Wilsoni.*	Zone of *Dicr. Clingani.*	Zone of *Pleur. linearis.*	Barren muds.	Zone of *Dicell. anceps.*	Zone of *Dipl. acuminatus.*	Zone of *Dipl. vesiculosus.*	Zone of *Mon. gregarius.*	Zone of *Dipl. cometa.*	Zone of *Mon. spinigerus.*	Zone of *Rastr. maximus.*	
Rastrites maximus, *Carr.*	...	...	...	...	...	...	...	...	...	...	...	C	*Lobiferus*-beds (Sweden).
—— capillaris, *Carr.*	...	...	...	...	...	...	...	...	...	...	...	R	
—— hybridus, *Lapw.*	...	...	...	...	...	...	...	...	...	r	C	...	Coniston Mudstones, Coalpit Bay (Ireland).
—— distans, *Lapw.*	...	...	...	...	...	...	...	...	...	...	...	R	Coniston Muds., Kieselschiefer.
—— peregrinus, *Barr.*	...	...	...	...	...	...	...	...	C	R	...	...	Coniston Muds., Kieselschiefer, Colonies, *Lobiferus*-beds, Coalpit Bay.
Monograptus turriculatus, *Barr.*	...	...	...	...	...	...	...	...	...	...	...	R	Coniston Mudstones, Colonies, *Lobiferus*-beds, Tieveshilly (Ireland), Lisbellaw.
—— Halli, *Barr.*	...	...	...	...	...	...	...	...	...	...	R	c	Coniston Muds., Colonies, *Retiolites*-beds (Sweden), Tieveshilly beds, Kieselschiefer.
—— Hisingeri, *Carr.*	...	...	...	...	...	...	...	...	...	...	C	c	Coniston Muds., Colonies, Kieselschiefer, *Lobiferus*-beds, Coalpit-Bay beds.
—— Becki, *Barr.*	...	...	...	...	...	...	...	...	...	...	...	C	Coniston Muds., Colonies, Kieselschiefer, *Lobiferus*-beds, Coalpit-Bay beds.
—— spinigerus, *Nich.* (=Sedgwicki, *Portl.*).	...	...	...	...	...	...	...	...	...	...	C	R	Coniston Muds., Colonies, Kieselschiefer, Pomeroy beds.
—— proteus, *Barr.*	...	...	...	...	...	...	...	...	...	R	R	R	Coniston Muds., Colonies, Kieselschiefer, Tieveshilly beds, *Retiolites*-beds.
—— runcinatus, *Lapw.*	...	...	...	...	...	...	...	...	...	...	...	c	*Lobiferus*-beds.
—— concinnus, *Lapw.*	...	...	...	...	...	...	...	...	r	r	...	...	Coniston Mudstones, Coalpit-Bay beds.
—— argutus, *Lapw.*	...	...	...	...	...	...	...	...	r	r	r	...	Coniston Muds., Coalpit-Bay beds.
—— intermedius, *Carr.*	...	...	...	...	...	...	...	...	...	...		R	Coniston Mudstones.
—— Clingani, *Carr.*	...	...	...	...	...	...	...	...	...	...	r		
—— spiralis, *Geinitz*	...	...	...	...	...	...	...	...	r	...	...	...	Coniston Muds., Colonies, Kieselschiefer, *Lobiferus*-beds, Coalpit-Bay beds.
—— communis, *Lapw.*, var.	...	...	...	...	...	...	...	...	C	...	...	...	Coniston Muds., Coalpit-Bay beds.
—— fimbriatus, *Nich.*	...	...	...	...	...	...	...	...	r	...	...	...	Coniston Mudstones.

Monograptus gregarius, *Lapw.*	...	...	...	...	...	...	...	...	C	c	...	...	Coniston Mudstones, Colonies, Kieselschiefer, *Lobiferus*-beds, Coalpit Bay.
—— attenuatus, *Hopk.*	...	...	...	...	...	...	...	r	r	r	r	r	Coniston Muds., Colonies, Kieselschiefer, Coalpit-Bay beds.
—— tenuis, *Portl.*	...	...	...	...	...	...	...	r	C	c	c	c	Coniston Muds., Kieselschiefer, Pomeroy, Coalpit Bay.
—— lobiferus, *M'Coy*	...	...	...	...	...	...	...	...	r	...	...	...	Coniston Muds., Kieselschiefer, *Lobiferus*-beds, Coalpit-Bay beds.
—— cyphus, *Lapw.*	...	...	...	...	...	...	...	...	C	...	...	...	Coniston Muds., Kieselschiefer, Coalpit-Bay beds.
—— leptotheca, *Lapw.*	...	...	...	...	...	...	...	...	r	r	...	...	Coniston Mudstones, Kieselschiefer (?).
—— Sandersoni, *Lapw.*	...	...	...	...	...	...	...	...	r	...	...	...	*Lobiferus*-beds, Coalpit-Bay beds.
—— triangulatus, *Harkn.*	...	...	...	...	...	...	...	...	c	...	...	...	Pomeroy, Kieselschiefer, Coalpit Bay, *Lobiferus*-beds.
Dimorphograptus (?) elongatus, *Lapw.*	...	...	...	...	...	...	r	r					
Diplograptus folium, *His.*, = palmeus+ovatus, *Barr.*	...	...	...	...	...	...	...	...	c	c	c	c	Coniston Mudstones, Colonies, Kieselschiefer, *Lobiferus*-beds, Pomeroy beds, Coalpit-Bay beds.
—— sinuatus, *Nich.*	...	...	...	...	...	...	...	...	...	c	c	c	Coniston Mudstones, Coalpit-Bay beds.
—— Hughesi, *Nich.*	...	...	...	...	...	...	...	...	c	c	c	c	Coniston Mudstones, Coalpit-Bay beds.
—— tamariscus, *Nich.*	...	...	...	...	...	...	...	...	C	c	c	c	Coniston Mudstones, *Lobiferus*-beds, Coalpit-Bay beds.
—— physophora, *Nich.*	...	...	...	...	...	...	...	...	R	...	...	...	Kieselschiefer (?).
—— vesiculosus, *Nich.*	...	...	...	...	...	...	...	C	r	...	...	...	Coniston Mudstones, Coalpit-Bay beds.
—— acuminatus, *Nich.*	...	...	...	...	...	...	C	...	...	...	...	...	Kieselschiefer (?).
—— truncatus, *Lapw.*	...	r	C	C	C	C	...	...	...	...	...	...	Utica Slate.
—— quadrimucronatus, *Hall*	...	...	...	c	...	...	...	...	...	...	...	...	Utica Slate, *Dicranograptus*-beds, Conway.
—— foliaceus, *Murch.*	C	C	C	c	...	...	...	...	...	...	...	...	Conway, Tiddyn Dicwm, Abereiddy B., *Dicranograptus*-beds, Carnalea beds (Ireland), Utica Slate, Norman's Kiln (H. R. G.).
—— angustifolius (*Hall*)	r	...	...	...	...	...	...	...	...	...	...	...	Upper Skiddaw, Norman's Kiln, Ballygrot.
—— tricornis, *Carr.*	c	c	...	...	...	...	...	...	...	...	...	...	Abereiddy Bay, Ballygrot beds, Skiddaw slates, Norman's Kiln.
—— dentatus, *Brongn.*	r	...	...	...	...	...	...	...	...	...	...	...	Skiddaw Slates, Point Levis, Llanvirn.
—— Whitfieldi, *Hall*	r	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, Tiddyn Dicwm.
—— cometa, *Geinitz*	...	...	...	...	...	...	...	...	...	C	...	...	Kieselschiefer, *Lobiferus*-beds.
—— insectiformis, *Nich.*	...	...	...	...	...	...	...	...	R				
—— penna, *Hopk.*	...	...	...	...	...	...	...	...	R(?)				
—— modestus, *Lapw.*	...	...	...	...	...	...	...	c	R	...	...	...	Coniston Mudstones, Coalpit Bay, *Lobiferus*-beds.

List of Species.	GLENKILN.	HARTFELL.					BIRKHILL.						Foreign localities.
		LOWER.			UPPER.		LOWER.			UPPER.			
		Zone of *Clim. Wilsoni.*	Zone of *Dicr. Clingani.*	Zone of *Pleur. linearis.*	Barren muds.	Zone of *Dicell. anceps.*	Zone of *Dipl. acuminatus.*	Zone of *Dipl. vesiculosus.*	Zone of *Mon. gregarius.*	Zone of *Dipl. cometa.*	Zone of *Mon. spinigerus.*	Zone of *Rastr. maximus.*	
Diplograptus perexcavatus, *Lapw.*	r	r	...	...	...	...	...	...	...	...	...	...	*Dicranograptus*-schists, Ballygrot.
Lasiograptus Harknessi, *Nich.*	r	r											
—— margaritatus, *Lapw.*	...	...	r										
—— ? bimucronatus, *Nich.*	c	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln (?), Tiddyn Dicwm.
Glossograptus Hincksi, *Hopk.*	r	r	...	...	...	...	...	...	...	...	...	...	? Norman's Kiln, Tiddyn Dicwm.
Clathrograptus cuneiformis, *Lapw.*	r												
Retiolites perlatus, *Nich.*	...	...	...	...	...	...	...	...	?	r	r	r	Coniston Mudstones, *Lobiferus*-beds, [Coalpit-Bay beds.
—— fibratus, *Lapw.*	...	...	r	r									
Climacograptus scalaris, *His.*	...	...	...	...	...	...	...	...	...	...	...	...	Coniston Mudstones, Kieselschiefer, *Lobiferus*- and *Retiolites*-beds, Coalpit-Bay beds, Pomeroy beds.
—— ——, var. normalis, *Lapw.*	...	...	...	...	...	?	C	C	C	c	c	c	
—— ——, var. rectangularis, *M'Coy*	...	...	...	...	...	...	...	...	c	...	...	...	Coalpit Bay, Colonies, Kieselschiefer.
—— ——, var. styloideus, *Lapw.*	...	...	...	R									
—— ——, var. caudatus, *Lapw.*	...	...	c										
—— ——, var. tubuliferus, *Lapw.*	...	...	...	c									
—— cælatus, *Lapw.*	c	...	...	...	...	...	...	...	...	...	...	...	Oslo beds (Norw.), *Dicranograptus*-schists.
—— Wilsoni, *Lapw.*	...	c											
—— bicornis, *Hall*	C	c	c	?	...	...	...	...	...	...	...	...	Norman's Kiln, Tiddyn Dicwm, Builth.
—— ——, var. peltifer, *Lapw.*	r	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln.
—— ——, var. tridentatus, *Lapw.*	r	r											
—— ——, var. tuberculatus, *Nich.*	...	...	...	...	...	c							
—— Scharenbergi, *Lapw.*	c	c	...	...	...	...	...	...	...	...	...	...	Abereiddy Bay, Tiddyn Dicwm, Llany Chevmedd, Oslo beds, *Dicranograptus*-schists.
—— innotatus, *Nich.*	...	...	...	...	...	...	...	r	r				
Leptograptus flaccidus, *Hall*	r	r	c	C	...	...	...	...	...	...	...	...	Lake St. John, Conway, Abereiddy Bay?
—— capillaris, *Carr.*	...	...	...	r									

Pleurograptus linearis, *Carr.*	...	...	...	C									
Amphigraptus divergens, *Hall*	...	...	...	r	...	...	...	...	...	...	...	...	Lorraine Shale (Utica Slates).
—— radiatus, *Lapw.*	...	?	r										[? Tiddyn Dicwm.
Cœnograptus gracilis, *Hall*	r	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, *Dicranograptus*-schists,
—— explanatus, *Lapw.*	R												
—— surcularis, *Hall*	r	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln.
—— nitidulus, *Lapw.*	R												[Tiddyn Dicwm.
Didymograptus superstes, *Lapw.*	c	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, *Dicranograptus*-schists,
—— serratulus, *Hall* (?)	R	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln.
Dicellograptus anceps, *Nich.*	...	...	...	...	...	C	...	...	...	...	...	...	*Trinucleus*-schists (Sweden).
—— Morrisi, *Hopk.*	...	...	c	C	...	...	...	...	...	...	...	...	*Dicranograptus*-schists, Conway.
—— Forchhammeri, *Geinitz*	r	r	C	?	?	...	...	...	...	...	...	...	Abereiddy Bay, Llandridod, Tiddyn Dicwm, Bornholm, *Dicranograptus*-schists.
—— elegans, *Carr.*	...	...	...	c									
—— divaricatus, *Hall*	c	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, Llanvirn.
—— moffatensis, *Carr.*	r	r											
—— caduceus, *Lapw.*	...	...	r										
—— pumilus, *Lapw.*	...	...	...	r									[Llandridod, Tiddyn Dicwm.
—— sextans, *Hall*	c	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, Abereiddy Bay ?,
Dicranograptus Clingani, *Carr.*	...	...	r	...	...	...	...	...	...	...	...	...	*Dicranograptus*-beds.
—— ramosus, *Hall*	R	?	c	...	...	...	...	...	...	...	...	...	Tiddyn Dicwm, Builth, Conway.
—— Nicholsoni, *Hopk.*	c	c	c	...	...	...	...	...	...	...	...	...	Tiddyn Dicwm, Montmorenci Falls.
—— formosus, *Hopk.*	R												
—— ziczac, *Lapw.*	c												
Thamnograptus typus, *Hall*	c	...	...	...	...	...	...	...	...	...	...	...	Norman's Kiln, Tiddyn Dicwm.
—— scoticus, *Lapw.*	R												
Corynoides calycularis, *Nich.*	c	c	c	...	...	...	...	...	...	...	...	...	Conway.
—— curtus, *Lapw.*	...	...	c	...	...	...	...	...	...	...	...	...	*Dicranograptus*-schists.
—— gracilis, *Hopk.*	...	...	?										
Dictyonema moffatensis, *Lapw.*	...	...	R										
Dawsonia campanulata, *Nich.*	...	...	...	...	...	...	...	...	c	c	c	R	
Acrotreta Nicholsoni, *Daws.*	...	...	R										
Discina, sp.	r	r											
Lingula, sp.	R	R											
Siphonotreta micula, *M'Coy*	...	...	R										
Peltocaris aptychoides, *Salt.*	...	...	...	...	...	...	...	...	...	...	R	R	
Aptychopsis Lapworthi, *Woodw.*	...	...	...	...	...	...	...	...	...	...	...	R	
Discinocaris Browniana, *H. Woodw.*	...	...	...	...	...	...	...	...	r	r	r		
Eurypterus, sp.	...	...	R										
Asaphus, sp.	R												

C. Conclusion.

§ I. *Systematic Importance of the Divisions of the Moffat Series.*

The black carbonaceous and ferriferous strata of the Moffat Series have often been compared to the thin-bedded argillaceous deposits, impregnated with iron and stained with vegetable matter, that bulk so largely in our British Coal-measures. It is, indeed, impossible to avoid this comparison. The rapid alternation of thin flaggy layers of nodular ironstone and carbonaceous and partially calcareous strata give to many of its sections* (especially those of the Birkhill division) a remarkable resemblance to hundreds that may be pointed out in the higher division of the Carboniferous system. These resemblances descend even to minute peculiarities. One of the most striking is the frequent association of a seam of black shale with a band of white or cream-coloured clay, which has been very aptly instanced† as reminding the observer of a coal-seam and its subjacent argillaceous floor or "under-clay."

Several mining speculators, relying solely upon these mineralogical resemblances, have sought in vain for coal in these beds. To the geologist they have been equally misleading. Accustomed to the rapid recurrence of strata of this nature in a great mass of sandstone rock, and finding, as it appeared, a similar arrangement almost everywhere throughout the Silurians of the south of Scotland, he could not fail to draw the inference that these black beds occurred upon several horizons in an enormous mass of arenaceous deposits.

In the case of the miner, an acquaintance with the geological position of the fossils of the carbonaceous shales would have effectually prevented his foolish expenditure of time and labour. Similarly, in the case of the geologist, it is our present knowledge of the vertical range of the fossils of the Moffat Shales which, above all other testimony, proves their identity in character, sequence, and physical relationships in every locality, clearing away at a single stroke most of the difficulties that formerly barred the path of the investigator, and rendering his task in the future a matter of ease and certainty.

Moreover it has shown conclusively that, beyond their superficial lithological resemblances, the Moffat Series have no features in common with the argillaceous and ferriferous Carboniferous strata with which they are usually compared. The Coal-measures were manifestly accumulated under what, geologically speaking, were rapidly varying physical conditions. Beds precisely similar recur again and again in the succession. The fauna remains unaltered through enormous thicknesses of rock, the same species reappearing invariably upon the resumption of similar physical conditions. On the other hand, the Moffat Rocks, though composed merely of a few hundreds of feet of black and variegated shales and mudstones, rarely or never show two bands that are precisely similar; nor do they anywhere throughout the succession in the present district afford the slightest evidence of hasty deposition. The collective

* Mem. Geol. Surv. Scotland, Explan. Sheet iii. pp. 11, 12.

† *Ibid.* Explan. Sheet iii. p. 11.

fauna, again, is even more strikingly contrasted. Although composed throughout of the same zoological groups, it shows a continued and most important change in its aspect as we follow it from the base to the summit of the formation. Not a single species is known to range through more than half its total thickness. Nowhere is there any adequate apparent cause for this extraordinary effect. Nowhere is there any reason for doubting that it is due to those gradual and cumulative changes brought about in every extended period of time.

In their general mineralogical features, and in their rapid variation in palæontological characteristics, the rocks of the Moffat Series are very different from any of the typical Silurians of the Principality. Among Palæozoic formations the only strata with which in these respects they admit of satisfactory comparison are the dark shales imbedding the calcareous rocks of Scandinavia, where the enormously thick Silurians of Wales are represented by less than 2000 feet of fossiliferous rock, and where each fossil has but a few feet of vertical range. Among Secondary deposits they may be paralleled with such formations as the Speeton Clay of the coast of Yorkshire, where the massive Upper Jurassic and Neocomian rocks of the Continent and the south of England are represented by less than 500 feet of dark shales and clays, in which each zone is marked by its peculiar Ammonite, and each fossil ranges through but a small fraction of the entire succession.

If these analogies are allowed their due weight (and every new fact gathered in the Moffat district adds something to their force), they inevitably lead to the deduction that the Moffat Rocks are the greatly attenuated representatives of enormous thicknesses of the Welsh Silurians, in which their fossils will be found to have a vastly extended range. In other words, there is a high probability that the *Divisions* of the Moffat Series have, in truth, a systematic importance equal, or at least approximating to that of the so-called formations of Siluria.

§ II. *Comparison of the Faunas of the three Divisions of the Moffat Series with those of their Foreign Equivalents.*

Owing to the great rarity in the Moffat Series of fossils belonging to the well-understood families of the Brachiopoda and Crustacea, which are universally regarded as the most trustworthy exponents of the geological age of their containing beds, we are forced to rely almost exclusively upon such evidence as may be afforded by their Graptolithina. In our comparative ignorance of the relationships and vertical distribution of the forms composing this peculiar group, all testimony derived from this source would, formerly, have been either wholly ignored by the geologist, or received with grave suspicion. Within the last few years, however, a sufficiency of evidence has gradually been accumulated, which places it beyond a doubt that these fossils are quite as restricted in their geological distribution as those of the better understood zoological groups. In the face of the complete, and indeed overwhelming, proofs of the truth of this fact, which follow from their vertical arrangement in the different zones of the Moffat Series, as detailed in the preceding portion of this paper, all reference to the identical results arrived at in other districts by British and continental palæontologists would here be superfluous.

That none of the Moffat Shales are of Arenig age is clear from the complete absence within them of those complex forms of *Dichograpti* and *Phyllograpti* which constitute so striking and characteristic a feature of the Graptolitic fauna of the Skiddaw Slate and its Welsh and Canadian equivalents. That none of them appertain to the true Upper Silurian, as at present understood by the majority of geologists, is fully as evident, from the fact that they are similarly destitute of all the known peculiar Upper Silurian forms. Our search for their extra-Scottish equivalents must therefore be restricted to the three successive formations of the Llandeilo, Bala, and Lower Llandovery. Let us pass the respective Graptolite faunas of these in review.

(a) *Llandeilo Formation* (*Llandeilo-Flags of* Murchison).

From the valuable and accurate papers of Mr. Hicks*, and the general results of the special study of the Welsh Graptolites made by Mr. John Hopkinson, we learn that the Llandeilo beds of South Wales, in the typical localities of Llandridod, Meadow Town, and Abereiddy Bay, have afforded the following species :—

Leptograptus flaccidus (*Hall*).
Dicellograptus divaricatus (*Hall*).
—— sextans (*Hall*).
Dicranograptus ramosus (*Hall*).
—— formosus (*Hopk.*).
Diplograptus foliaceus (*Murch.*).
—— dentatus (*Brongn.*).
—— tricornis (*Carr.*).
Climacograptus cælatus (*Lapw.*).
—— Scharenbergi (*Lapw.*).

The general facies of this assemblage is clearly that of the Glenkiln Shales, in which all the foregoing species are abundant, and to which in South Scotland many are strictly peculiar. In South Wales, however, they are almost invariably associated with forms of *Didymograptus* of the type of *D. Murchisoni*, and sometimes with species of *Phyllograptus*, none of which have ever been detected in the Moffat Series.

In one locality among the Llandeilo beds of North Wales these distinctive forms are absent. The dark shales in the hills a few miles to the north of Tremadoc, which have been mined for copper, but whose precise position is yet undetermined, have afforded to Messrs. Salter † and Hopkinson ‡ the following species, all of which are common Glenkiln forms :—

Dicellograptus divaricatus (*Hall*).
—— sextans (*Hall*).
Dicanograptus ramosus (*Hall*).
Cœnograptus gracilis ? (*Hall*).
Diplograptus foliaceus (*Hall*).
—— ? Whitfieldi (*Hall*).
Diplograptus ? Hincksi (*Hopk.*).
—— tricornis (*Carr.*).
Climacograptus bicornis (*Hall*).
—— Scharenbergi (*Lapw.*).
Didymograptus superstes (*Lapw.*).
Thamnograptus typus ? (*Hall*).

Judging from the absence of *Didymograptus Murchisoni* and of the genus *Phyllograptus*, and the presence of some of the succeeding Bala

* Quart. Journ. Geol. Soc. vol. xxi. pp. 180 &c.
† Mem. Geol. Survey, vol. iii. plate xi. fig. 1.
‡ Coll. John Hopkinson, Esq.

forms, it may be inferred that this band of dark shale and therefore the Glenkiln Shales themselves are of the Upper or highest Llandeilo age.

This inference is greatly strengthened by the facts obtainable in the Llandeilo strata of Central Sweden, where the greater portion of the Llandeilo formation of Britain is represented by the well-known Orthoceras-Limestone. Upon this limestone reposes the sheet of dark shales denominated by Dr. Linnarsson* the Middle Graptolitic Schists. The lowest beds of this deposit, which, according to Törnquist, are most intimately associated with the underlying limestone, afford abundant examples of *Phyllograptus* and the *Murchisoni*form species of *Didymograptus*. These, however, soon disappear, and the highest beds that can be satisfactorily assigned to the Llandeilo formation afford the strikingly peculiar Glenkiln forms:—

Didymograptus superstes (*Lapw.*).
Cœnograptus gracilis (*Hall*).
Climacograptus Scharenbergi (*Lapw.*).
—— perexcavatus (*Lapw.*).

But it is on the continent of North America that we meet with the most complete representatives of the Glenkiln Shales. The dark shales and flagstones that bound the valley of the Hudson in the neighbourhood of the city of Albany were originally assigned by American geologists †, on imperfect data, to the Lorraine and Utica-Slate formation (Cincinnati Group), which everywhere overlies the Trenton Limestone. Their geographical position, their perfect agreement in rapid convolution and amount of alteration with the neighbouring Quebec (Taconic) Rocks, together with the comparatively ancient facies of the small group of fossils they afford, force us to regard them rather as forming the highest division of the so-called Quebec Group, whose greatly disturbed beds are believed by Professor Sterry Hunt ‡ and others to emerge unconformably from below the horizontal Trenton Limestones. On this view the Hudson-River Shales stand in the place of the higher Llandeilo beds of Britain.

At Norman's Kiln, in the Valley of the Hudson, on the Marsouin River, on the Lower St. Lawrence, and elsewhere they yield Graptolites in some abundance. From the figures and descriptions of Professor Hall the palæontologist can easily identify the following Glenkiln species §:—

Dicellograptus sextans (*Hall*).
—— divaricatus (*Hall*).
Cœnograptus gracilis (*Hall*).
—— surcularis (*Hall*).
Dicranograptus ramosus (*Hall*).
Diplograptus tricornis (*Carr.*).
—— Whitfieldi (*Hall*).
Diplograptus foliaceus (*Murch.*).
—— angustifolius (*Hall*).
Climacograptus bicornis (*Hall*).
Thamnograptus typus (*Hall*).
Didymograptus serratulus (*Hall*).
—— superstes (*Lapw.*).
Corynoides calycularis (*Nich.*).

Even the peculiar Glenkiln species absent from these American strata are represented by intimately allied forms. Thus:—

* Linnarsson, MS. Compare also Dr. Törnquist, Œfvers. af K. Vet.-Akad. Förhandlingar, 1871.

† Emmons's Amer. Geol. vol. i. p. 47.

‡ Hunt, 'Chemical and Geological Lectures.'

§ Prof. Hall, 'Palæont. New York,' vol. i. pls. 72 and 73, vol. iii. pp. 495 *et seq.*; Grapt. Quebec Group, p. 54.

Glossograptus Hincksii	is represented by	Glossograptus ciliatus (*Emm.*).
Dicranograptus ziczac	,, ,,	Dicranograptus furcatus (*Hall*).
Climacograptus Scharenbergi	,,	Climacograptus scalaris (*His.*).
Clathrograptus cuneiformis	,,	Clathrograptus Geinitzianus (*Hall*).

Thus, if the evidence from fossils be appealed to as indicative of the geological age of the Glenkiln division, the facts already adduced point unequivocally to a position in the Llandeilo formation as at present understood. The complete absence of the *Didymograpti* of the type of *D. Murchisoni*, and of the genus *Phyllograptus*, so common in the lower beds of that formation in Wales and Sweden, compels us to assign it to the very highest division of the Llandeilo, immediately at or not far below the base of the Caradoc or Bala.

(b) *Bala or Caradoc.*

The Upper Llandeilo age of the Glenkiln Shales having been thus definitely settled, we naturally turn to the strata of the succeeding Bala formation in search of the Graptolites of the Hartfell Shales.

Unfortunately for our purpose, it happens that in Siluria and the greater part of North Wales the rocks of this formation are of too arenaceous a character to afford Graptolites. In one locality only are they yet known to occur in comparative abundance, viz. in the cliffs to the N.W. of the town of Conway, where Mr. Hopkinson has collected * :—

Leptograptus flaccidus (*Hall*).
Diplograptus quadrimucronatus (*Hall*).
—— truncatus (*Lapw.*).
—— foliaceus (*Murch.*).
Corynoides calycularis (*Nich.*).
Dicranograptus ramosus (*Hall*).
—— Nicholsoni (*Hopk.*).
Dicellograptus Forchhammeri (*Gein.*).
—— Morrisi (*Hopk.*).

In Sweden the lowest beds of the Bala formation are represented by the highest division of Linnarsson's *Dicranograptus*-schists, which contains the following Hartfell species † :—

Dicellograptus Forchhammeri (*Gein.*).
—— Morrisi (*Hopk.*).
Dicranograptus ramosus (*Hall*).
—— Clingani (*Carr.*).
Diplograptus foliaceus (*Murch.*).
—— quadrimucronatus (*Hall*).
Corynoides calycularis (*Nich.*).
—— curtus (*Lapw.*).

In North America, as is well known, the higher Bala beds are represented by the Lorraine and Utica Shales (Cincinnati Group) that everywhere overlie the Trenton Limestone. They afford the common Hartfell forms ‡—

Leptograptus flaccidus (*Hall*).
Amphigraptus divergens (*Hall*).
Diplograptus foliaceus (*Murch.*).
—— truncatus (*Lapw.*).
Dicranograptus ramosus (*Hall*).
—— Nicholsoni (*Hopk.*).
Diplograptus quadrimucronatus (*Hall*).

None of the foregoing species have ever been met with in beds of Lower Llandovery age, and only three or four in the Upper Llandeilo, viz. those species which are also common to the Glenkiln and Hartfell Shales of Moffat. Thus the palæontological evidence of

* Coll. Mr. Hopkinson. Compare also Mem. Geol. Survey, vol. iii. pl. xii. fig. 1.

† Coll. Dr. Linnarsson.

‡ Nicholson (Collection); Hall, Grapt. Quebec Group, pp. 143, 144; Hall, Pal. New York, vol. iii. Supp. fig. 509; Logan, Geol. of Canada, p. 200.

the age of the Hartfell beds, though less perfect than that obtainable with respect to the underlying division, nevertheless places it beyond a doubt that they stand in the place of some of the Bala beds of Siluria.

(c) *Lower Llandovery.*

The Lower Llandovery rocks of Wales, in which the fossils of the third division of the Moffat Series might be expected to occur, have not as yet been thoroughly searched for Graptolites; nor has a single species of the Birkhill fauna been hitherto recorded from any of the Silurians of the principality.

In the Lake-district, however, the Coniston Mudstone, which occupies a corresponding stratigraphical position above the representatives of the Bala Limestone, is crowded with Graptolites. At Skelgill and Knock it yields the following Birkhill forms *:—

Rastrites hybridus (*Lapw.*).
—— peregrinus (*Hall*).
—— distans (*Lapw.*).
Monograptus turriculatus (*Barr.*).
—— Halli (*Barr.*).
—— cyphus (*Lapw.*).
—— communis (*Lapw.*).
—— fimbriatus (*Nich.*).
—— lobiferus (*M'Coy*).
—— Hisingeri (*Carr.*).
—— gregarius (*Lapw.*).
Monograptus attenuatus (*Lapw.*).
—— spiralis (*Gein.*).
—— tenuis (*Portlk.*).
—— argutus (*Lapw.*).
Diplograptus vesiculosus (*Nich.*)
—— tamariscus (*Nich.*).
—— Hughesi (*Nich.*).
—— sinuatus (*Nich.*).
—— folium (*His.*).
Retiolites perlatus (*Nich.*).
Climacograptus normalis (*Lapw.*).

It is needless to insist upon the precise agreement of this fauna with that of the Scottish deposit in question.

Nor is this agreement less striking when the comparison is made with the faunas of the Graptolitiferous Llandoveries of the continent of Europe. It will be seen from the Table inserted in my brief memoir on the Scottish Monograptidæ (Geol. Mag., Dec. 1876) that the Kieselschiefer of Thuringia, placed by Murchison and others at the junction of the two Silurians, afford almost all the Birkhill fossils, and that many of them are found in the "Colonies" which bridge over the palæontological gap between the Lower and Upper Silurians of Bohemia.

In the *M.-lobiferus* beds, which form the inferior division of Dr. Linnarsson's Upper Graptolite Schists and overlie every thing in Sweden to which the name Bala can be applied, the strictly Birkhill assemblage occurs which is given below †:—

Rastrites maximus (*Carr.*).
—— peregrinus (*Barr.*).
Monograptus lobiferus (*M'Coy*).
—— Hisingeri (*Carr.*).
—— spiralis (*Gein.*).
—— triangulatus (*Harkn.*).
—— Sandersoni (*Lapw.*).
—— spinigerus (*Nich.*).
Monograptus runcinatus (*Lapw.*).
—— gregarius (*Lapw.*).
Diplograptus folium (*His.*).
—— tamariscus (*Nich.*).
—— modestus (*Lapw.*).
—— cometa (*Geinitz*).
Climacograptus scalaris (*His.*).
Retiolites perlatus (*Nich.*).

Not one of these species descends into the underlying limestones

* Nicholson, Quart. Journ. Geol. Soc. vol. xxiv. pls. xix., xx., &c.

† Linnarsson (Collection). See also Törnquist, Œfvers. af K. Vet.-Akad. Förhandl. 1874, no. 4, p. 26.

and schists of Bala age, and only a few survive into the overlying *Retiolites*-beds (Mayhill?).

Similar facts might be cited from Brittany, Spain, Ireland, &c., but no further evidence is required to prove that the Birkhill Shales are of Lower Llandovery age.

§ III. *General Conclusions regarding the Age, Geological Relationships, and Conditions of Deposition of the Three Divisions of the Moffat Series.*

1. The evidences actually at our command regarding the vertical distribution of the fossils of the Moffat Series in the Silurian rocks of Europe and America thus conclusively establish the high systematic importance of its three main divisions, already deduced by us from their general lithological and palæontological characteristics. The three faunas which in South Scotland are characteristic of the three successive *Divisions* of the Moffat Series prove to be elsewhere as strikingly characteristic of the three successive *formations* that form the upper portion of the Cambro-Silurian system.

2. At the same time it cannot fail to be noticed that the vertical distribution of the Graptolithina among the Silurian rocks of the southern portion of Britain, Scandinavia, Central Europe, and North America agrees exactly in all the common forms, species for species, with that worked out by us in our detailed study of the black shales of the Moffat district. We are thus furnished with a complete palæontological demonstration of the truth of our interpretation of the geological succession in the Moffat Series.

3. In future the Glenkiln Shales must be considered as the equivalents of the highest division of the Llandeilo formation of Siluria; the Hartfell Shales as the attenuated representatives of the Bala or Caradoc formation; and the Birkhill Shales as standing in the place of the Lower Llandovery.

The lower portion only of the Hartfell Shales appears to be represented among the extra-Scottish Graptolitiferous deposits, and invariably by strata inferior in geological position to the Bala Limestone. If this be true, the Upper Hartfell Shales must occupy approximately the place of the Bala Limestone of Wales and its foreign equivalents.

The Birkhill Shales have been shown to belong to the lower half of the Middle Silurian (Llandovery formation of Murchison). If, therefore, the plan of making the Upper Silurian commence at the base of the Lower Llandovery, as advocated by Sir Charles Lyell, Mr. Hicks, and others, be generally adopted, the line of demarcation between the Hartfell and Birkhill Shales must form the uppermost limit of the Lower or Cambro-Silurian of the south of Scotland.

4. It may be objected by those who are familiar with the Upper Llandeilo, Bala, and Lower Llandovery formations of Wales, where each of these formations is composed of several thousands of feet of varied rock-matter, and characterized by a very diversified fauna, that it is highly improbable that they can have so degenerated in the insignificant geographical interval which divides Siluria from the south of Scotland, as to be represented in the latter region only by

three thin rock-bands, each about a hundred feet in thickness, almost inseparable mineralogically, and destitute of all traces of their former inhabitants beyond a few Graptolites and Phyllopoda.

There is, however, a complete answer to this objection. The Lower Llandovery, of such vast extent in Cardigan and Merioneth, has dwindled down to the thickness of the Birkhill Shales in the intervening area of the Lake-district, where it forms the Coniston Mudstones, a group of beds almost identical in thickness, lithology, and palæontology with the equivalent Scottish deposit of the Birkhill Shales.

The Caradoc formation of Siluria, estimated by Murchison as above 6000 feet in thickness in the typical area of Shropshire, is reduced to less than half these dimensions in the Berywn Hills of Merioneth. Here, also, it begins to take on the mineralogical characters of the Hartfell Shales, its lower beds, according to Prof. Jukes, becoming more and more of the nature of black slate as we approach the town of Conway *. In the Lake-district the whole formation appears to be represented by less than 300 feet of calcareous shales.

The same attenuation most certainly takes place also in the underlying formations. The diversified Upper Llandeilo formation (of Murchison), consisting in the typical areas in South Wales of several thousands of feet of schist, sandstones, and limestone, is represented in the Berwyns and Arenigs by a homogeneous sheet of dark shales of no great vertical extent. As we approach the shores of the Irish Sea the formation has so thinned out as no longer to be individually recognizable, the Lingula-flags, Tremadoc, Arenig, Llandeilo, and Bala being all possibly included in the contracted sections between the summit of Snowdon and the Lower Cambrian beds to the east of Caernarvon.

Nor is this extraordinary north-westerly attenuation of the Lower Silurian rocks a phenomenon exclusively confined to Britain. On the contrary, it is one of the most striking features of the Lower Silurians of Europe in general. In Bohemia and Brittany, as well as in Siluria, the Lower Silurian rocks are known to be of enormous vertical dimensions, consisting everywhere of highly arenaceous strata, rarely exhibiting any trace of true limestones. Further to the northward, viz. in Bornholm and the Baltic provinces of Russia, they have all dwindled to a thickness of less than a thousand feet of impure limestones and schists. In Sweden and Norway, to the extreme north-west, these limestones rapidly thin away, till finally nothing remains but a few calcareous zones imbedded in a sheet of dark Graptolite-schist †.

* Jukes and Geikie's 'Manual of Geology,' 1872, p. 536.

† We have an excellent illustration of the same fact in the Moffat district itself. Each of the higher zones of the Moffat Series retains all its characteristics absolutely unaltered when followed along the strike of the beds from N.E. to S.W., but varies to a most remarkable extent in its successive reappearances in the sections visible in the direction of the dip. The same rule holds good even among the overlying greywackes to such a degree that several geographical zones are recognizable, each with a distinct lithological character, and each traceable in the line of strike from sea to sea.

In brief, the vertical dimensions, lithology, and palæontology of the Lower Silurian rocks of Western Europe and Britain are practically invariable when the beds are followed in a N.E. and S.W. direction; while they change simultaneously, and to a large but progressive extent, in all these characters when they are traced from south-east to north-west. The geologist, therefore, aware of these facts, might safely have inferred *à priori* that the Llandeilo, Bala, and Lower Llandovery deposits of the south of Scotland, which lie in the general line of strike of the Scandinavian Silurians, would, in all probability, resemble them in their essential features. This, as we have seen, is undoubtedly the case; and the Moffat Series can therefore no longer be regarded as in any way anomalous. On the contrary, they are very naturally defined as British Silurians of the Scandinavian type, being simply the south-westerly prolongation of the sheet of dark Graptolitic schist, of whose vertical continuity the prolific Lower Silurian Limestone bands of Sweden are brief and local interruptions.

5. The consideration of the physical and zoological relationships of the rocks of the Moffat Series to those of the equivalent Silurians of Girvan, the Lake-district, and the north of Ireland is best deferred till the exposures in the Lammermuirs, Leadhills, and Galloway have been described in detail and all the facts are before us. Nevertheless it is perhaps allowable in this place to call attention to the highly significant facts of the remarkable lithological homogeneousness and insignificant vertical thickness of the Moffat Series in the district already described, together with the perfect identity in type of its successive faunas, so clearly distinct specifically. For these facts there appears to be but one common explanation. They point almost irresistibly to the conclusion that these strata must have been laid down in an area removed in some way from the irregular and disturbing influences of river-deposits and current-action, and in which the general physical conditions of the sea-bed remained practically unaltered from the middle of the Llandeilo to the close of the Lower Silurian epoch.

§ IV. *Bearing of the foregoing Conclusions upon the general Question of the Succession among the Lower Silurian Rocks of the South of Scotland.*

It only remains in conclusion to indicate as briefly as possible the bearing of the foregoing results upon the general question of the succession among the Lower Silurians of the south of Scotland.

In this connexion it is highly satisfactory to observe not only that our conclusions appear to be in complete accordance with all the facts universally admitted among those who have made these rocks a subject of special study, but that at the same time they furnish us with a thorough elucidation of many strange anomalies which have hitherto sorely perplexed the cautious investigator.

(*a*) All the black bands yet detected among the Scottish Silurians contain fossils of identical species and varieties with those afforded by one or other of the zones of the Moffat Series, as described in the foregoing pages, while these fossils are distinct from those in the surrounding greywackes. Bearing in mind the rigid vertical restriction of these fossils to definite zones both in the Moffat Series and in their foreign equivalents, it is impossible to doubt that each and all of these black bands are due to the repetition of the same deposit of the Moffat Shales.

(*b*) Recollecting further the fact of the rapid north-westerly attenuation of the Lower Silurians in Britain and Western Europe, together with that of the gradual disappearance of the highest zones of the Birkhill beds when the latter are followed in a corresponding direction even within the limited area of the Moffat district, we cannot fail to perceive that upon each consecutive repetition the Moffat Series should diminish in collective thickness, and that its fossiliferous zones should disappear one by one from above, as we pass over the Uplands from south-east to north-west.

I shall show upon a future occasion that this is what does actually take place. In the Dobb's-Linn band, as we have seen, all the zones are present. In the Meggat and Hartfell bands, a few miles to the north-west, the highest zone has disappeared. At Bogrie, yet further in the same direction, a few feet only of the *D.-vesiculosus* and *M.-gregarius* bands are all that remain to represent the great Birkhill division of our typical area. On the next reappearance of the series to the north of Dalry, the Birkhill division has wholly disappeared, and the *Pleurograptus*-zone of the Lower Hartfell Shale is almost in contact with the greywackes. The same rule holds good to the extreme north-west limit of the Uplands, where scarcely any thing more than a greatly degenerated representative of the Hartfell-Glenkiln division is apparent.

(*c*) This furnishes us with a clue to a paradoxical circumstance, hitherto perfectly unaccountable to the palæontologist, and puzzling alike to those who held the theory of the identity in geological age of the various black bands, and those who preferred rather to consider those to the northward as belonging to a newer formation than the Moffat series—namely, that as we pass from south to north, the fauna of the black bands, instead of remaining comparatively unaltered, or affording evidence of a gradual change into one of a more modern type, undergoes, on the contrary, a rapid and most peculiar impoverishment. In the southern district, though Bala-Llandeilo forms are certainly present, those characteristic of extra-Scottish Llandovery beds are distinctly predominant. In the central areas the Llandovery forms have all disappeared, and the commonest forms are those of Bala age; while to the extreme north, and therefore in what at first sight appear to be the highest beds, few remain but what are universally admitted to be strictly Llandeilo species.

(*d*) As no fossils of older date than those of the lowest or Glenkiln division of the Moffat Series have ever been discovered in the Southern Uplands, while the base of that division is nowhere visible *, it may be regarded as almost certain that the strata of the black

* The Girvan district is here regarded as a distinct and separate area.

bands everywhere emerge from below the surrounding greywackes in anticlinal forms, as in the Moffat district. If this be the case, all the greywackes that floor the Uplands from St. Abb's Head to the Mull of Galloway necessarily belong to one and the same great arenaceous group, which must be of newer date than the Moffat Series, and therefore, generally speaking, of Llandovery age.

This conclusion is in exact accordance with what is already known of the fauna of the arenaceous deposits to the north of the Moffat area. Though the facts are somewhat complicated by the replacement in the Girvan area of the dark beds of the Moffat Series by limestones and breccias containing Bala and even Llandeilo fossils, yet in the intervening districts of Peebles, Leadhills, and Moniave, where the Hartfell and Glenkiln divisions are still recognizable, it has been clearly shown by the officers of the Geological Survey of Scotland that the conglomerates nearly at the base of the greywacke group are often crowded with fossils (Corals, Crustacea, and Brachiopoda) of well-known Llandovery types.

To the south of the Moffat district this agreement is even more striking. The great greywacke group to the south of the Ettrick was proved by us, in the earlier portion of this paper, to repose upon the Birkhill (Lower Llandovery) Shales of the Moffat Series. After undergoing innumerable repetitions among the desolate wilds of Eskdalemuir, in the contorted and inverted attitudes of their equivalents in the Moffat area, the beds of this great group gradually roll over to the southward, and pass up steadily, by a conformable and gradual lithological and organic transition, into the *Riccarton Beds* of Kirkcudbright, Mosspaul, and the Slitrig, which are acknowledged on all hands to be the representatives of the Wenlock Shale of Siluria.

(*e*) Geologists have long been aware of the presence of a chain of enormous volcanos in the Lake-district of the north of England, which vomited forth mountain-masses of lava and ashes throughout the greater portion of the Llandeilo epoch. Those who accepted the theory of the Llandeilo age of the dark shales and greywackes of the south of Scotland, and attempted to correlate them with their supposed equivalents on the south of the Solway, have frequently expressed their astonishment that these Scottish deposits, which must have been laid down in a sea in some places less than 30 miles distant from the volcanic area of the Lake-district, yet showed no trace whatever of contemporaneous igneous action, whether in the form of trap-dyke, lava-flow, or bed of volcanic ash.

Our conclusion that the oldest beds of the south of Scotland (the Glenkiln Shales) are in reality the equivalents of the highest Llandeilo rocks, read in conjunction with the recent determination of the absence of the highest Llandeilos in the Lake-district owing to the break between the Borrowdale and Coniston groups, as worked out by Mr. Aveline and the officers of the Geological Survey, rids us at once of this vital difficulty. It is not only possible, but indeed highly probable, that the volcanic series of Cumberland are represented by similar rocks in the south of Scotland. They are, however, at present buried almost everywhere beneath strata of later age, the lowest visible formation (the Glenkiln Shales) succeeding the volcanic series in point of time, and filling up the interval which is unrepresented in the Lake-district.

(*f*) In fine, the facts and inferences detailed in the present paper lead us step by step to the important conclusion that the Lower Silurian rocks of the Southern Uplands are actually arranged in two distinct formations, namely, a lower and very thin group of fine-grained Graptolitic Shales, and an upper and comparatively massive series of arenaceous strata. The latter, though not in reality of extraordinary thickness, is so excessively plicated that it floors more than three fourths of the entire Silurian area, the underlying black shales being visible only at rare intervals along the axes of a few of the more important folds.

Here, then, for the first time, do we begin to realize the fulfilment of the confident prediction of Sir Roderick Murchison, that these apparently interminable Silurian rocks would be found to be, in truth, of reasonable dimensions. The great arenaceous Llandeilo formation of the earlier geologists has utterly vanished, and in its stead we find a few hundreds of feet of argillaceous shales. The Bala beds are proved to be related to those of the underlying formation in identity of lithological character and in physical conformity, as everywhere in Britain and Western Europe generally, where their natural relations have not been disturbed by an excess of igneous activity. We have, indeed, become unexpectedly aware of the presence of a more than ordinary thickness of Middle Silurian rocks; but even these may be satisfactorily paralleled with equivalent strata of corresponding vertical dimensions in the long misunderstood areas of Cardigan and the Thüringer Wald.

EXPLANATION OF PLATES XI.–XIII.

Plate XI.

General maps, showing the geographical distribution of the rocks of the Moffat Series in the typical area of the Moffat District.

Plate XII.

Map and sections of the Moffat rocks of the typical locality of Dobb's Linn, Moffatdale.

Plate XIII.

Plans of the chief exposures of the Black Shales of the Moffat District.

Discussion.

Mr. Warington W. Smyth inquired as to the great break described by the author as occurring at the limestone shown in the sections, where it appeared that above the limestone there were forty or fifty species which do not extend downwards, and below it forty or fifty species which do not pass up. He wished to know whether this indicated a real break in the life of the period, or whether it was due to imperfect investigation of the deposits.

Mr. Hicks remarked on the evident difficulty of the ground investigated, and said that, without the combination of the thorough knowledge of Graptolites and the keen perception of petrological characters possessed by the author, such an explanation of its structure as was given in his paper would have been impossible. He remarked that the great folds described were not uncommon in Silurian countries, and that the succession of rocks described was similar to, if not identical with, that occurring in Wales and in the Lake-district. The break at the Coniston Limestone indicates a change in the physical history of the earth at that period, and is the first break we know of after the commencement of the Cambrian.

Mr. Carruthers remarked that many years ago he had been thoroughly acquainted with the district described, and had pointed out that the Graptolites in this region were of very local occurrence, and often strictly confined to particular beds; but his geological knowledge was not at the time sufficient to warrant him in attempting to work out the stratigraphical results of his observations. From his knowledge of the district, however, he felt convinced that the author had offered a most simple and satisfactory explanation of its excessively complicated structure. He thought that in Mr. Lapworth's paper we shall obtain a base-line for the correlation of all the Silurian beds of the south of Scotland.

Prof. Ramsay wished to indicate that there was another side to the question. Prof. Geikie and his assistants in the Geological Survey of Scotland had observed the occurrence of the black shales referred to; but in Lanarkshire they recognized the existence of a set considerably higher in the series than the Moffat shales, and separated from them by a considerable thickness of shales and grits. In Shropshire and Wales there is a great leap from the Caradoc to the Upper Llandovery, and it seemed to him that part of the Scotch beds, which contain a remarkable mixture of Lower and Upper Silurian Mollusca, might represent the deposits missing in the more southern area.

Prof. Judd remarked that only by such careful and detailed palæontological investigations as those of the author was it possible to hope to find a key to the true succession of strata so folded, crumpled, and broken up as those of the Silurians of the South of Scotland.

Prof. Hughes pointed out that if Mr. Lapworth got the whole series in one continuous section, as indicated on the wall, it was extremely improbable that great grits should be intercalated close by. He did not know the district, but the interpretation put upon the section by Mr. Lapworth agreed very well with what we should expect from the manner in which the May-Hill beds of S. Wales die out and, where we should expect them in N. Wales, the Corwen Grits, Tarannon Shales, and black bands come in, succeeded by the Denbigh Flags; and then, nearer Moffat, in the Lake-district, an almost exactly similar series, but more like the Moffat section, with abundant fossils in the black bands similar to those associated with the Tarannon Shales of N. Wales. These, which were the Graptolithic Mudstones of the Lake-district, he recognized in Mr. Lapworth's Birkhill group. To complete the story, in Scandinavia, on the other side of Mr. Lapworth's sections, we have the whole series represented by from 250 to 1000 feet; yet the details are very similar. Having, by a question, obtained from Mr. Lapworth the opinion that the strongest break in the Moffat series was at the base of the Birkhill group, which, by the association of fossils elsewhere, seemed to be the equivalent of the Lower Llandovery, he pointed out that we have here additional evidence in favour of bracketing the Upper and Lower Llandovery together, and taking them as the base of the Silurian.

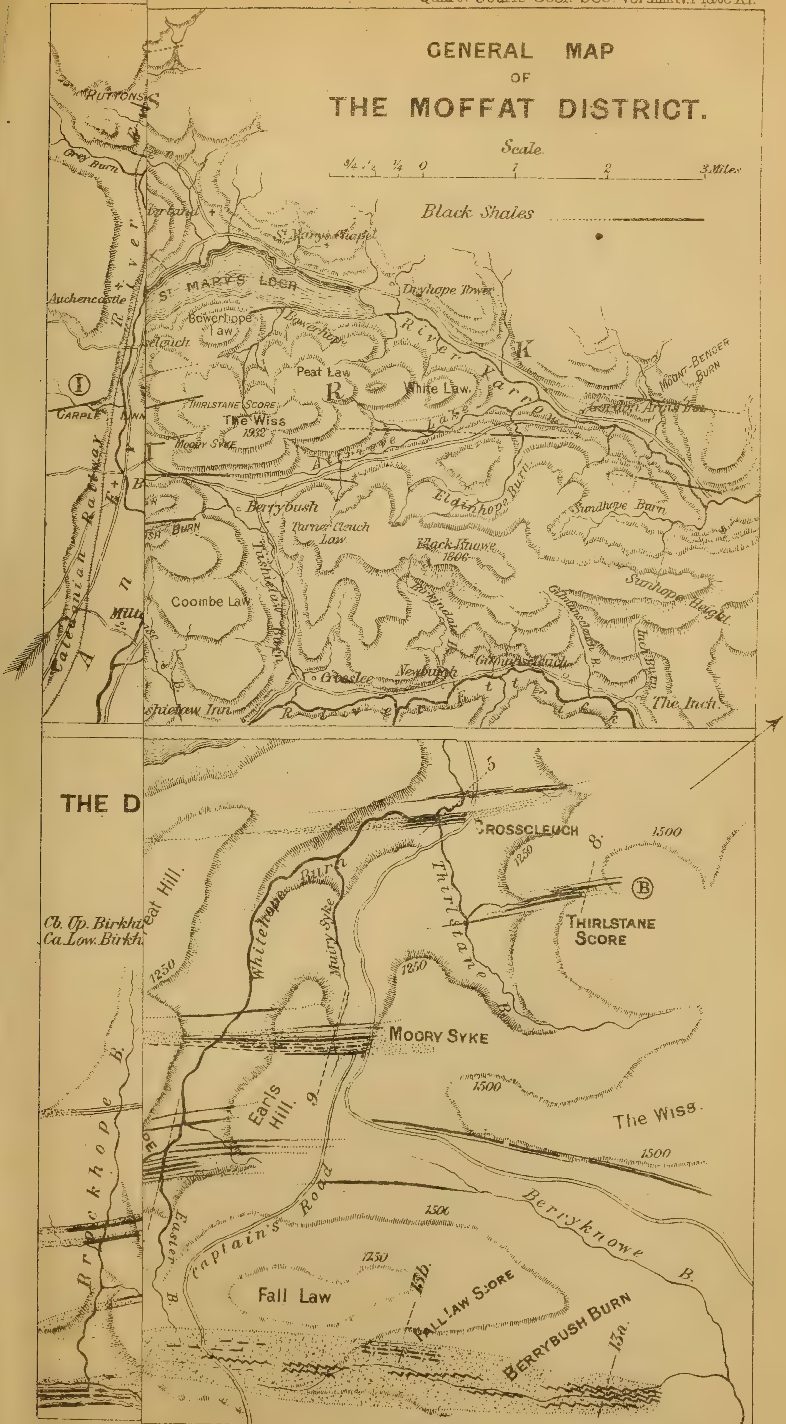
The Author regretted that in the limited time at his disposal he had been unable to lay before the meeting more than a small fraction of the physical and palæontological evidence upon which his conclusions were founded. If, however, it was conceded that the typical sections had been correctly interpreted, and that the succession of organic forms therein was in precise agreement with that in England and Europe, much of the remainder followed almost of necessity.

In answer to Prof. Ramsay, the author replied that the general theory of the succession among the South Scottish Silurians adopted by the Scotch Survey was dependent solely upon broad generalizations from the apparent order of superposition, in districts where it is admitted that in any single visible section it is impossible to be certain whether we are ascending or descending in the order of the beds. It leaves all the anomalies of the Scotch beds unexplained, and is crowded with insuperable difficulties. It places in a single subdivision of the Llandeilo formation a thickness of comparatively barren beds almost equal to that of the whole thickness of the fossiliferous Silurian elsewhere. The black beds near the supposed base of this immense formation swarm with Graptolites peculiar to the Llandovery rocks of other countries. Thousands of feet higher in the succession these wholly disappear, and few are met with but peculiar Bala forms; while, at the very summit of the formation, the only survivors are either strictly Llandeilo forms, or have come up from the Arenig itself.

With regard to the two supposed unconformities alluded to, it was admitted by the Professor himself that no physical proofs were forthcoming in support of them. In fact the supporters of this theory have been driven to adopt these breaks in order that they may not be compelled to relinquish their fundamental hypothesis that there is more than one main band of black shales. The proofs brought forward in the present paper that all the bands of black shale in the Moffat district rise along anticlinal lines render that hypothesis untenable, and rid us at once of the necessity for any unconformity whatever.

As for the calcareous beds of Girvan &c., which contain, in immediate juxtaposition and apparent intermixture, Brachiopoda &c. elsewhere peculiar to beds of Llandovery, Bala, and Llandeilo age, it was almost certain that towards the N.W. of the southern uplands (as in Sweden, &c.) the black beds are in great part replaced by calcareous rocks, and that we have there a parallel instance of what takes place in the Moffat district, the three distinct Graptolitic faunas of Moffat (whose accidentally intermingled fossils may often be there collected from the talus of a single cliff) being paralleled by the three testaceous faunas of Girvan &c. When it is recollected that in certain localities these shell-bearing rocks are highly conglomeratic, in others involved, shattered, and more or less metamorphosed, it is probable that in some spots many of the forms are derivative, and in others that they owe their apparent intermixture to a variety of accidents.

In answer to Mr. Hicks and Prof. Hughes, the author said that the chief palæontological break in the south of Scotland occurred at the base of the Birkhill shales, *i.e.* between the Bala and Lower Llandovery beds. There is no physical break at this horizon, and the zoological break is apparent only where the Moffat beds are typically developed. Where the Birkhill beds lose their black-shale bands as they pass to the northward, it is impossible to draw a line of demarcation between the Llandoveries, both Upper and Lower Llandovery being probably represented by the greywackes of Peebles and Lanarkshire.



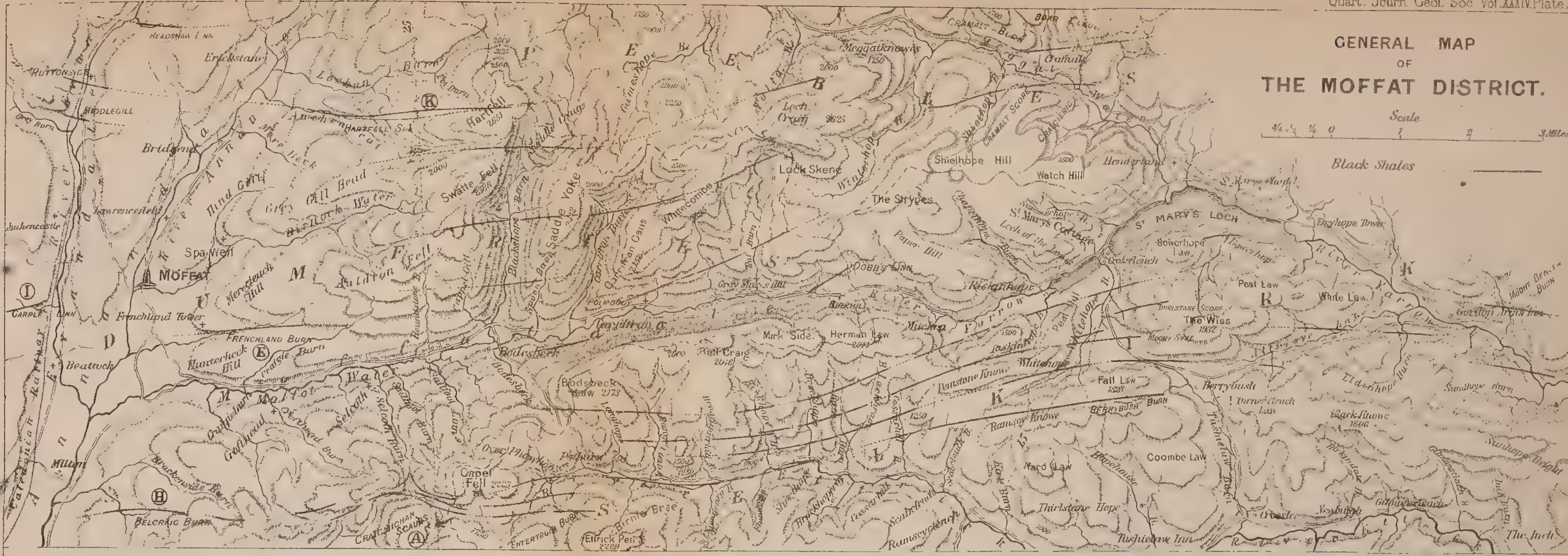
Chas. Lapwo[rth]

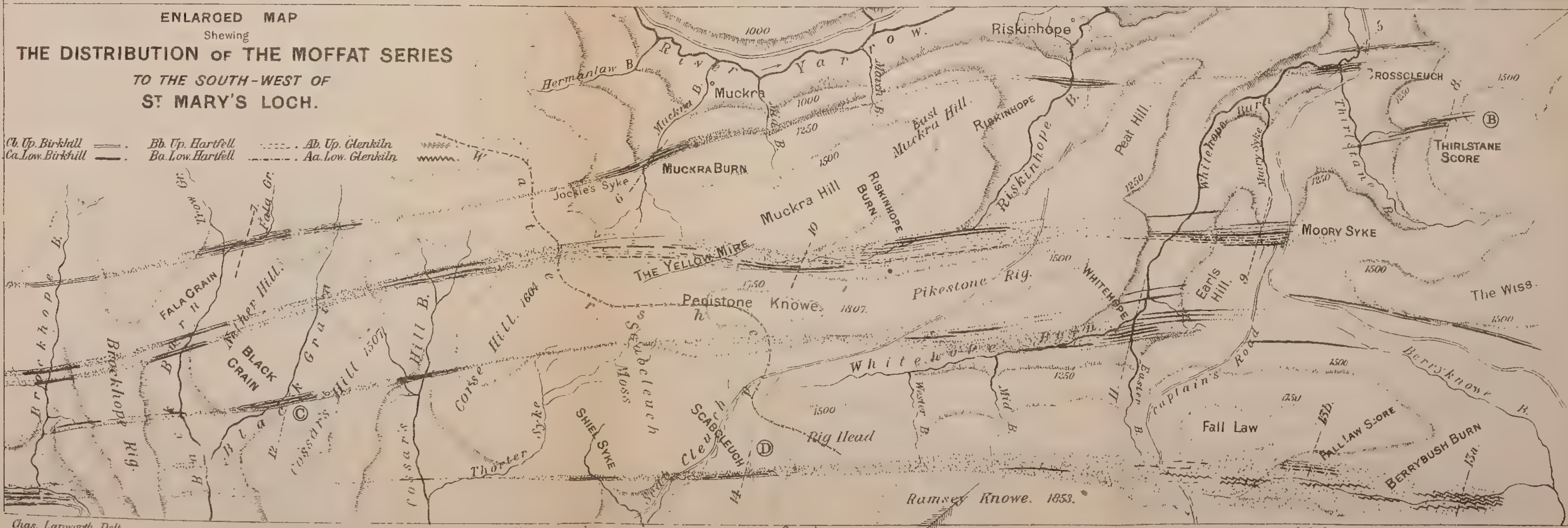
2 miles. 1, 2, 16. References to Sections.

F. Dungerfield, lith. London

Geographical Distribution of the Moffat Series.

Quart. Journ. Geol. Soc. Vol. XXXIV. Plate XI.





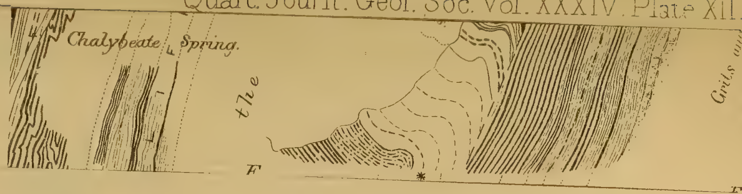
Chas. Lapworth, Delt.

Ⓐ. Ⓒ. References to enlarged Plans on Plate XIII

Scale. 1 mile 2 miles.

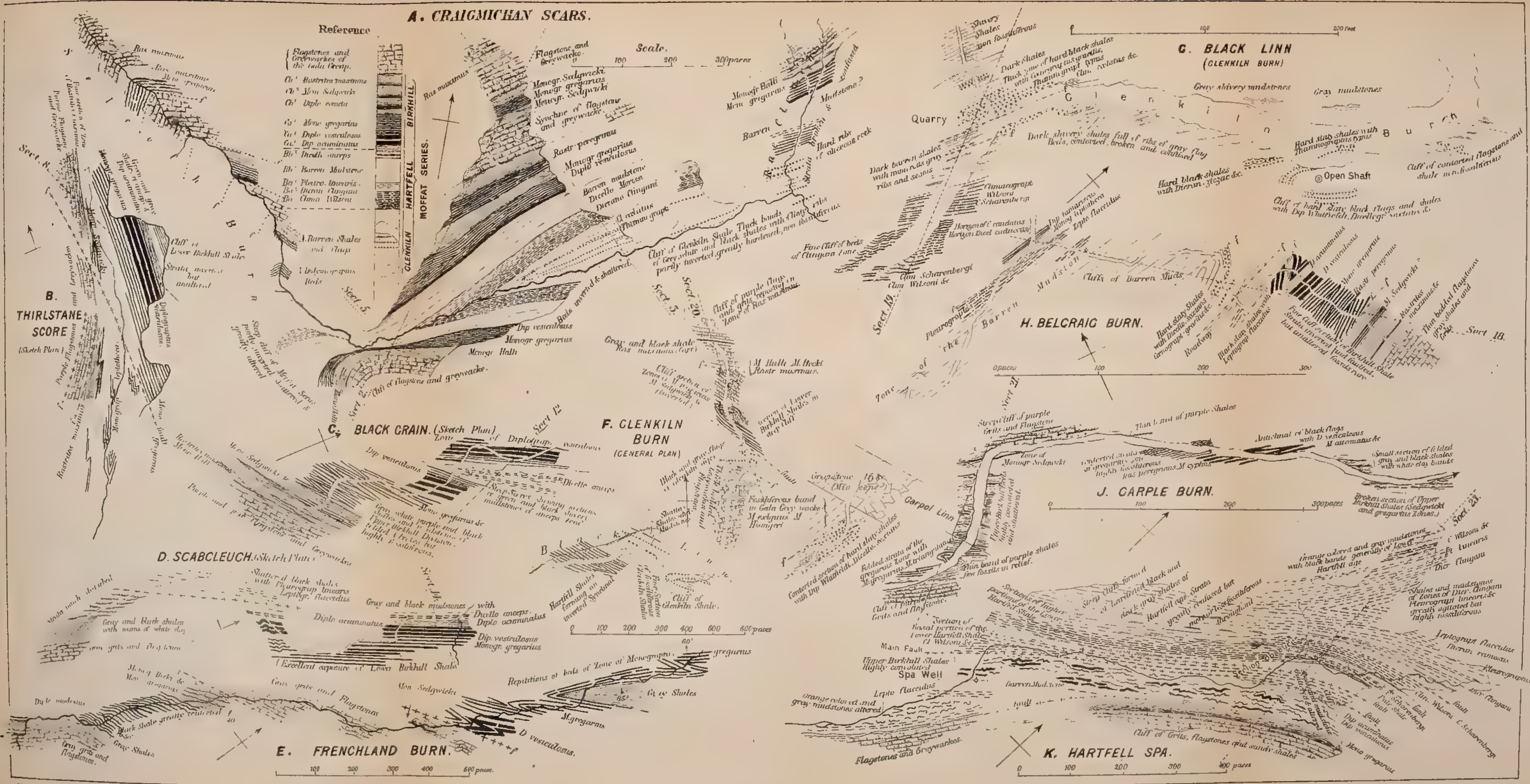
1, 2, 16. References to Sections.

F. Dangerfield, lith. London


Chalybeate Spring.
the
F
Grits
F


MAP AND SECTIONS of the MOFFAT ROCKS of the Typical locality of DOBB'S LINN.
Scale: 0 100 200 300 400 500 feet
SECTION I. NORTH CLIFF. (along line A-B.)
SECTION II. MAIN CLIFF (C-D.) (Typical Section.)
SECTION III. SOUTH CLIFF (along line E-F.)
BIRKHILL SHALES
East Fault
Main Fault
West Fault
THE CORRIE
W SCORE
MID SCORE
E SCORE
LONG CLIFF
LONG BURN
Waterfall
Greenstone Dyke
Dyke
Section of Upper Birkhill Shales
Chalybeate Spring
Promontory Strata obscured by talus and vegetation
West Score
Middle Score
East Score
NORTH CLIFF
SOUTH CLIFF
MAIN CLIFF
EAST CLIFF
DOBB'S LINN
Gala Group
Grits and Flagstones
Upper Birkhill
Lower Birkhill
Upper Hartfell
Lower Hartfell
HARTFELL SHALES
GLENKILN SHALES
Reference.
GALA GROUP
MOFFAT SERIES
Alluvium
Grits and Flagstones
BIRKHILL SHALES Upper Lower
Zone of Rastr. maximus Cb
Zone of Mon. spinigerus. (Horizon of M. Clingani)
Zone of Diplogr. cometa. Cb
b (Rastrites peregrinus)
Zone of M. gregarius Ca
a (Mono. Sandersoni)
Zone of D. vesiculosus Ca
Zone of D. acuminatus Ca
Zone of Dicello anceps Bb
HARTFELL SHALES Upper Lower
Barren Mudstone Bb
(Fossiliferous Seam)
Zone of Pleuro. linearis Ba
Zone of Dicr. Clingani Ba
Zone of Clima. Wilsoni Ba
GLENKILN SHALES Upper
Zone of Didy. superstes

PLANS OF THE CHIEF EXPOSURES OF THE MOFFAT SERIES.



Chas Lapworth 1877.

Dangerfield Lith 22 Bedford St Covent Garden

20. *Notes on the* Physical Geology *of the* Upper Punjáb. By A. B. Wynne, Esq., F.G.S., Geological Survey of India. (Read February 20, 1878.)

[Plate XIV.]

Contents.

1. In December of the year 1873 I brought before the Society some features in the physical geology of the Upper Punjáb *. Observations which I have made since then, together with information derived from those of others, enable me now to offer some additional notes on this country, more detailed accounts of which will be found in the publications noted below †.

2. The principal additions to our knowledge of the geology of this and neighbouring regions, obtained since my last communication was written, have been gathered from the following operations:—

The trans-Indus salt region has been examined and reported upon ‡, the arrangement of the rocks leading to the inference that the vast local deposits of rock-salt and gypsum are much newer than those of the cis-Indus Salt Range—the salt of one region being little if at all older than Eocene, and of the other not newer than Silurian.

* Quart. Journ. Geol. Soc. vol. xxx. p. 61.
† Records Geol. Surv. Ind. vols. vi. p. 59, vii. p. 64, viii. p. 46, x. pp. 140, 223.
‡ Mem. Geol. Surv. Ind. vol. xi. pt. 2.

The observations of the Geological Survey of India have been extended to the ground between the Simla outer Himalayan area and the Ráwal Pindí* plateau, the gap which formerly existed there having been filled up by the examination of the Jamú Hills † and the Pír-Panjal range ‡.

Some further acquaintance has been made with the outer Himalayan hills north of the Ráwal Pindí plateau, and this plateau itself has been mapped, as well as the small Kharian ridge lying between the eastern part of the Salt Range and the Jamú-Kashmır mountains.

At several places in or near the Ráwal-Pindí plateau large additions to the collections of Siwalik fossils have been made by Mr. Theobald, and several new or otherwise interesting forms have been described by Mr. Lydekker §.

Mr. Ball's visit to some ground beyond the western frontier of the Punjáb ||, to inspect a reputed coal-locality, has shown the structure of the border mountains in that direction.

In Mr. Medlicott's paper on the Jamú district ¶ is pointed out the gradual disappearance of several unconformities in the outer Himalayan tertiary zone, as the rocks extend towards this part of the Punjáb, although the disturbed abnormal contact of the whole zone with the older Himalayan rocks remains strongly marked throughout, except at the west base of the Daulahdár range **, where the junction rock is in "a semimetamorphic trappoid condition." From the differences between the stratigraphic relations in the Simla area and in the valley of the Jhelum, he concludes that the middle parts of the Himalaya mountains, near the former area, were elevated at a much earlier period than those to the westward, towards the Jhelum valley and the Hindú Kúsh ††. He also notices a post-tertiary formation or high-level river shingle in the Jamú area, apparently analogous to the superficial deposit included as "post-tertiary or drift" in the first two columns of the Table given at p. 63 of my former paper (vol. xxx.). (See opposite page.)

4. Before proceeding, I would call attention to the description of the general structure of this country in that communication, and to the Table itself, showing, so far as can be at present traced, the corresponding formations in the following directions, viz.:—in the Salt Range, in the outer Himalayas of this country, in those of the Simla area, and the presumably representative groups of the central Himalaya region. To that Table may now be added the corresponding classification of the rocks between the northern Punjáb and the Tien-Shán mountains, taken from Dr. Stoliczka's Yarkand and Kashgar papers ‡‡, as well as those given by Messrs.

* In English "Rawul Pindee," from an older town (or Pind) situated on the river Rawal some miles to the east.

† Jumoo. Peer Punjal.

‡ Messrs. Medlicott and Lydekker. Rec. Geol. Surv. Ind. vol. ix. pp. 49, 155.

§ Records Geol. Surv. Ind. vol. ix. pp. 42, 86, 154, vol. x. pp. 30, 76.

|| Records Geol. Surv. Ind. vol. vii. p. 14.

¶ Records Geol. Surv. Ind. vol. ix. p. 49.

** Daoladár.

†† Hindoo Koosh. Records Geol. Surv. Ind. vol. ix. p. 51.

‡‡ Records Geol. Surv. Ind. vol. vii. pp. 12, 49, 81, vol. viii. p. 13.

3. *Comparative Table of Formations* (*continued from* p. 63, vol. xxx. Quart. Journ. Geol. Soc.).

	Himalayan and High Asian Trans-Himalaya (Stoliczka).	Pír Panjal and Jamú Hills (Medlicott and Lydekker).	Luní Pathan Hills, parts of Afghanistan and Beluchistan (Ball).
ALLUVIAL...............	Gravels and sands, Artush Province.		
POST-TERTIARY	....	High-level river-shingle...........................	(Siwalik beds below?)
PLIOCENE...............	.... "Artush beds," clays and sands, conglomerates; Neogene.	Upper Siwalik, conglomerates, clays, sands; Lower Siwalik, sandstones and clays; bones.	Siwalik sandstones and conglomerate. No fossils obtained. (UNCONFORMITY.)
MIOCENE?	....	"Murree beds," "Red Rocks," clays and sandstones. .... Sirmús.	Nahan?
EOCENE	Grey and reddish sandstones, shales, conglomerates, *Nummulites* and *Melania*; Indus valley, Leh, Kium.	Sabathu brown, olive, and red clays, and Nummulitic limestone with some coaly shales.	Nummulitic limestone group. Sandstones, coaly and green-shale group.
CRETACEOUS...........	Coarse grey calcareous sandstones and chloritic marls, *Gryphæa vesicularis*.	....	.... ?
JURASSIC	....	....	....
TRIASSIC	Limestones with *Dicerocardium himalayaense*, *Megalodon triqueter*, spherical corals, &c.: Changlang, Karakorum, Koktan ridge, &c.	Schists, shales, and limestones along S.W. base of Pír Panjal.	
	(UNCONFORMITY.)		
CARBONIFEROUS	Dark shales, sandstones, quartzose schists, with *Bellerophon*, *Productus semireticulatus*, *Athyris*, *Terebratula*, new: Lingzi-thang, Karakorum, Chakmak, Bash-sujun.	Limestones, with *Fenestella* at one locality: Shartalla, Riassi, Dandli, in Jamú (and Kashmír also).	
SILURIAN	Dark shales, red conglomerates, schistose and chloritic rocks. Ranges between the Upper Indus and Turkistan.	Purple and white quartzites, black coaly shales, dark blue earthy limestone: Kiol series. Both flanks of Pír-Panjal range.	
CAMBRIAN...............	....	Black and brown slates and quartzites: Pír-Panjal range; metamorphic.	
CRYSTALLINE	Syenite and Gneiss................................	Gneiss of Pír Panjal.	

Medlicott and Lyddeker for the Jamú Hills and the Pír-Panjal range, lying between the British portion of the Upper Punjáb and the valley of Kashmír, also the upper portion of the geological series as represented in the frontier country * visited by Mr. Ball (see Table, p. 349).

All the geological systems or formations named in the first columns of these Tables being represented in the region under notice (except that the Cambrian formation has not been here identified as such), it will be sufficient for me to give, in the form of a somewhat more detailed list than formerly appeared, the main character of the various groups and formations, recalling the observation that a wide petrological dissimilarity marks the whole series of the adjacent outer Himalaya, as compared with the same series, so far as this is represented, in the extra-Himalayan region of the Salt Range †.

None of the palæontological relations of these formations have been as yet worked out or published in full, a difficulty reduced, however, so far as relates to the identification of the older rock groups, by Dr. Waagen's inspection of the fossil-bearing beds in the field, and one, which his present occupation upon the pre-Tertiary fossils of the Salt Range will do much to remove.

A small sketch map (Pl. XIV.) annexed (the outline for which is taken from Montgomery's 'Kashmír Route Map') will convey the dispositions of the Palæozoic, Mesozoic, and Cainozoic rocks, and also show several of their subdivisions ‡.

Upper Punjáb Rocks §.

Alluvium and later detrital ....16.	Ordinary alluvium and subrecent "fan" deposits.

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* Of the Luní Pathans.

† Referred to also by Dr. Waagen. See 'Zeitschrift der deutschen geologischen Gesellschaft,' vol. xxviii. p. 664.

‡ In this map the now customary Indian official spelling of names is given. In the text, where the official form might mislead, the spelling according to the English sounds is given also, or added at foot of the page.

§ It is as well to correct in this place a few points in my former paper. Since it was written the Siwalik beds called Miocene at p. 62 have been thought more probably Pliocene, a correction which should be carried out in the Table there annexed. The Tagling limestone, in the last column of this Table, should have been represented as Liassic rather than Triassic, according to Dr. Stoliczka (Mem. Geol. Surv. Ind. vol. v. pt. 1). The group No. 5 in the present list has been omitted in the former list of Salt-range groups. At pages 64 and 65 the name "Siddur" should be read "Liddur" in the footnotes. At p. 68, line 14 from bottom, for "Nahun" read "Dagshai." The conjecture at the end of Section 14, p. 70, with reference to the occurrence of Nummulitic limestone bands at Oorí in Kashmír was not supported by a subsequent examination; and the sectional representation of the rocks at Dundelee, copied on p. 74, has since been corrected by Mr. Medlicott. The limestone c^1 is not thought to be presumably Krol; the carbonaceous beds c^2 are Nummulitic, and therefore do not underlie c^1 as represented (Rec. Geol. Surv. Ind. vol. ix. p. 53). This correction also applies to the end of Section 6, p. 64, and to the second paragraph of Section 14, p. 70.

POST-TERTIARY ....15.	Loess and pebble-beds, the pebbles local limestone or crystalline rocks.	
PLIOCENE (Lydekker) ...14.	"Upper Siwaliks"—coarse conglomerate clays and soft grey sandstone. "Lower Siwaliks"—grey sandstone and red clays; chief ossiferous group.	
MIOCENE? ....13.	"Murree beds"—grey and purple sandstones, purple and red clays.	
EOCENE........................12. (including upper salt beds)	"Sabathu"—earthy light-coloured limestones, grey sandstones, deep purple and greenish clays, gypsum. The rock-salt and gypsum trans-Indus occur at the base of a Nummulitic group of this aspect.	
	EXTRA-HIMALAYAN.	HIMALAYAN.
	Salt Range and to the west, trans-Indus.	of the outer hills near the Ráwal-Pindí plateau.
		Dislocation.
	Pale Nummulitic limestones with a band of coaly shale and alum-shales below.	Dark limestones with fewer *Nummulites* and olive-brown shale.
CRETACEOUS...............11.	Olive sandstones, conglomerates, dark boulder-shale, blackish shale, and yellow sandstone.	Light-coloured limestone, and a thin group of impure ferruginous limestone.
JURASSIC ....10.	White or light-coloured sandstone, shales, limestone, golden oolite, variegated sandstones, and clays.	Dark limestones, shales, of grey or black colour (Spiti shales), sandstones rarely.
		Unconformity.
TRIASSIC.......................9.	Limestones and greenish shales, a limestone conglomerate. Red clays and thin sandstones with salt-crystal casts to the eastward.	Hard limestones, slaty shale, sandstones, some hæmatitic layers. Dolomite, *Dicerocardium*- and *Megalodon*-limestones; whole formation thick, chiefly of limestones.
INFRA-TRIASSIC ....8.	....	Siliceous dolomite overlying red sandstones and shales at Sír-Ban mountain.
		Unconformity.
CARBONIFEROUS ....7.	Limestone, dolomite, shale, and sandstone; numerous fossils.	Unknown in this district, represented in the Púnch and Jamú area.
? ....6.	Speckled sandstone, red and lavender clays; age unknown with certainty.	

		Extra-Himalayan.	Himalayan.
?	............5.	Magnesian sandstone and dolomite sandstone.	
Silurian	....................4.	*Obolus*- or *Siphonotreta*-beds, clunchy dark shales, sandy and conglomeratic layers.	Dark slates of Attock, Hazára, &c., sandstones, limestones. Unfossiliferous. Probably Silurian.
Saline Series (Silurian or older.)	............3.	Lower or purple sandstone passing down to "red gypseous marl," gypsum, and rock-salt; thin layers of dolomite with salt-crystal casts in the red salt-marl.	
Metamorphic	............2.	....	Part of the Attock slates in Hazára, slightly.
Crystalline	...............1.	....	Syenite and "central gneiss"?
Igneous	....	A few small exposures of volcanic rock. Greenstone and doleritic dykes &c. in No. 4.	

Having thus shown the general geological series to be found in this and some of the neighbouring countries, the deposits and conditions which they indicate here in the Upper Punjáb may be briefly described.

5. Palæozoic. *Oldest Rocks.*

Regarding the crystalline rocks, I have little information to present; they do not occur largely in accessible portions of the district, except in the form of transported detritus. Of the more lofty regions beyond the British frontier, it may be gathered, from the papers referred to, that syenite and gneiss form the fundamental rocks; and Dr. Stoliczka remarks that these two crystalline varieties pass into each other, the same crystalline masses assuming different forms in the high country traversed by the Yarkand and Kashgar Embassy in 1873–74.

The midrib of the Pír-Panjal range is of gneiss, which reappears in the Kyjenâg* range north of the Vedusta or Upper Jhelum river, and has been found by Dr. Waagen and myself forming high mountains in the northern part of the Hazára district beyond Abbottabad. It is an easily recognized rock, rendered porphyritic by large twin crystals of white felspar (orthoclase). From Hazára westward the more crystalline rocks pass beyond the British frontier to the north of Yusufzai, where their occurrence is recorded, by Drs. Bellew and Verchère, as far west as the junction of the stream from the Bajaor † mountains with the Lunda ‡ or Kâbul river. Mica-schist is also mentioned as occurring beyond the Yusufzai frontier; but I have not seen it in Hazára, nor does Mr. Lydekker record its occurrence in the Pír-Panjal range.

* Pronounced Kawj-e-nawg. † Bajowr.

‡ Loonda. I am informed that limestone also occurs in the mountains north of Murdan, Yusufzai.

Cambrian and Silurian.

6. Succeeding the more crystalline rocks are masses of contorted azoic slates in the outer Himalayan regions, some of which are semi-crystalline or metamorphic, and alternate with quartzites or trappoid rocks on the Pír Panjal. These slates have not been found in a highly metamorphosed state within the range of my observations; but silky slates and beds decomposed to a substance like porcelain clay have been found in Hazára. Greenstone dykes and masses were also met with.

A portion of this slate series has been classed as Cambrian by Mr. Lydekker, and another, less metamorphic, containing coaly shales and limestones, as Silurian.

I have provisionally referred the slates and limestones of Attock, and the slates of Nowshera and Hazára, to the Silurian period, for the reason given in a footnote at p. 65 of my former paper*.

Very different from these is the older portion of the extra-Himalayan series of the Salt Range. Here a thin group of less than 200 feet of dark clunchy shales, in which I found numbers of little *Oboli* (or *Siphonotretæ*) of two species, represents the Silurian rocks. Below these is a thick group of dull purple sandstones, without fossils, the place of which is taken in some western parts of the range by dark-coloured conglomeratic shale enclosing quantities of crystalline boulders of kinds not recognizable among the Himalayan detritus. The lower part of this "Purple-Sandstone" group becomes earthy, and passes downwards into the great red gypseous marl and salt-bearing group of the range, present almost everywhere along its southern foot. The salt-marl has been estimated at more than 1000 feet in thickness; and where the section is best known, the upper 500 feet of it is occupied by massive alternations of rock-salt beds overlain by thick beds of white gypsum, 250 feet of the salt-beds (some of them in solid zones 200 feet in thickness) being almost chemically pure salt†.

A small lenticular deposit of potash salt (sylvine with kieserite‡) was found some time ago in one of the more earthy saline layers by Dr. Warth, Collector of Customs, in charge of the mines. It is possible that other deposits of the kind may exist and yet remain unknown; for the ease with which the common salt is obtained in so many places close to the surface seems always to have rendered it unnecessary to explore the ground§.

It would appear that there were at this Silurian or Cambro-Silurian period seas depositing silts, sandstones, and limestones in

* The discovery of Silurian fossils in detritus from the Khybur range &c. Quart. Journ. Geol. Soc. vol. vii. p. 38.

† None of this Salt-range salt has, so far as I know, been examined for the rare metals.

‡ See Records Geol. Surv. Ind. vol. vii. p. 64, 1874.

§ At least until Government had a shaft and drift made to seek for the common salt beneath Mount Tilla, nearer to the railway than the present mines at Khewra, and not carried to a conclusion, so far as I know.

the Himalayan area, while in the Salt-Range region there was an enormous accumulation of gypseous marl taking place, in which stratification is seldom observable, unless marked by the occasional presence of layers of gypsum or dolomite, or towards the top by the thick bands of gypsum and rock-salt. Over these, sandstones were laid down, succeeded by dark-coloured mud and calcareous glauconitic layers, deposited by waters which contained, at least, some forms of organic existence (*Obolus*).

7. The mystery in which the origin of rock-salt is involved makes it difficult to imagine why this old deposit should be limited to the narrow area of the Salt Range and a few miles beyond the Indus. How far it may extend beneath the Ráwal-Pindí plateau it is impossible to say, but that it does not very suddenly die out seems likely from the occurrence of the salt-marl and saline springs in faulted exposures on the north of the range. I have estimated that there is in the neighbourhood of the outcrop, roughly speaking, a quantity of the mineral equal to nine cubic miles, or in round numbers enough to represent all the salt of a body of sea-water half a mile deep and 700 to 800 square miles in superficial extent.

The mode in which the salt occurs is in simple alternations of thick pure translucent bands, with other thick bands containing a large proportion of clay. The stratification of the salt is well marked, even in the purest bands, by numerous laminæ of different texture or colour; and it shows the effects of disturbance in the same way as other stratified rocks, by inclination and curvature. The thick beds of pure gypsum, as a rule, overlie it. No visible foreign matter, except the clay*, enters into the composition of either of these rocks; but both have sometimes a blotched or brecciated look, produced by more compact or more crystalline lumps, in the case of the salt lying in a more earthy matrix.

With regard to the supposition that this enormous deposit of rock-salt may be attributed, as is usually done, to the evaporation of an isolated salt-water lake, lagoon, or backwater, I am unacquainted with any instance of the recent formation of salt in this manner which does not become insignificant when compared with the hundreds of feet of solid salt accumulated at the Salt Range, or in the other salt region of this country. The recent deposits of Carmen Island, and those taking place round the shores of the Caspian, may be larger or deeper than those of the Run of Kutch, for instance; but I have been unable to obtain a record of their thickness† or the depth of their basins.

Even if the seas of the period were more saline, or evaporation more rapid, it appears that neither of these conditions would account for the observed association of gypsum with and overlying the rock-salt.

It is strange that the only igneous rock found *in situ* in the Salt

* And in rare instances iron pyrites or quartz in small crystals in the gypsum.

† The Caspian deposits are treated of in Von Baer's papers, Bulletin de l'Académie Imp. des Sciences de St. Pétersbourg, vols. xiii., xiv., xv.

Range is closely associated with the gypsum and salt beds of this saline series as intercalated lenticular masses of several feet in thickness. The rock is a purple volcanic one rendered porphyritic* by abundant minute acicular crystals of a mineral resembling actinolite. A paler purple ashy-looking layer accompanies it; and though the exposures are of limited extent, the association recalls the occurrence of trachytes and dolerites with the rock-salt of Hormuz at the entrance to the Persian Gulf †.

The dolomite layers in the salt-marl sometimes exhibit very perfect casts of what are known as "hopper crystals" of salt; but no trace of a fossil has been found in the whole saline series.

The purple-sandstone group overlying the salt-marl, gypsum, and salt is but slightly, if at all, saline, and is as unfossiliferous as the rocks below.

The finer beds of the Himalayan slaty region may have been accumulating in a deep sea the shore of which lay in the direction of the place occupied by the early Salt-range deposits; for there are indications of the existence of land towards peninsular India to the southward, in the crystalline boulders of the dark earthy conglomerates replacing the purple sandstone in western parts of the range. These crystalline boulders not being of the same kinds as the Himalayan detritus, it is a fair conjecture that they came from another direction; and the nearest rocks to the Salt Range exposed to the southward, those of the Karána hills, about 40 miles distant, consist of grey, ripple-marked and siliceous slate, brown, ferruginous quartzose sandstone, and greenish quartzite ‡, all such as might occur near more crystalline rocks.

There may be larger signs of volcanic agency concealed, and this force might have operated towards producing some local conditions at the place where the salt was deposited; all such traces are, however, absent in the other Salt region of the country.

Organic traces appear to be very rare in these older rocks, and limited, so far as known, to the Silurian shells in the Salt Range, and possibly the Carbonaceous layers of the Kiol group in the Pír Panjal.

8. Following the Silurian zone of the Salt Range with perfect conformity is a strongly marked belt of siliceous and highly magnesian rocks, the "Magnesian Sandstone group" (No. 5). It is only developed in the eastern part of the region, apparently on a somewhat lower horizon than another group of thick sandstones and red or lavender clays (No. 6) in greatest force about the middle of the range, and there underlying the Carboniferous formation.

These groups are both unfossiliferous; they have no representatives in the outer Himalayan hills that I know of, unless an equivalent for one or both be found in the unfossiliferous siliceous dolomite and red sandstones, shales, and hæmatites of the infra-

* In the sense of containing separated crystals.

† Records Geol. Surv. Ind. vol. v. p. 42.

‡ Dr. Fleming's and Mr. Theobald's papers, Journ. Asiat. Soc. Beng. vol. xxii, &c.

Triassic group resting unconformably upon the slates beneath Sír Ban * in Hazára, No. 8 in the list.

9. All the rocks, from the crystalline basement of Hazára up to, and above, both this infra-Triassic and these old Salt-Range groups (Nos. 5 and 6), present more or less the appearance of disturbance, greatest in the Himalayan direction and least marked in the eastern Salt-Range region. At the base of the northern infra-Triassic group, also, has been observed the first interruption in the sequence of the Upper Punjáb rocks. The unconformity showing this is complete, being accompanied by palpable evidence of the denudation of the underlying slates. Yet no trace of it has been found in the Salt Range. It marks a period of disturbance and elevation in the Western-Himalayan area indefinitely pre-Triassic, and which, from the absence, so far as can be proved where it occurs, of the Carboniferous and immediately underlying Salt-Range groups †, most probably took place at an early post-Silurian period.

The indications of adjacent land, at least partly formed of crystalline rocks, unlike those of the Himalayan area, still continue in the conglomerates of the extra-Himalayan group, No. 6 in the list (p. 351).

Carboniferous.

10. There are no Devonian rocks known anywhere in this part of the country; nor, in the absence of organic remains from groups 5, 6, and 8, is there any distinct representative of the Old Red Sandstone; so that we find the Palæozoic formations passing upwards from the Silurian period, in the Salt Range, through magnesian and arenaceous rocks of doubtful age, into conformable earthy, sandy, and calcareous Carboniferous deposits. In the Himalayan region the unconformity just now noticed may have interrupted the succession; but a possibility exists that the unfossiliferous infra-Triassic beds of Sír Ban may belong to this period. Sandstones, dolomites, and hæmatites of Carboniferous age occur elsewhere, though in the extra-Himalayan region seldom without associated beds containing ample fossil evidence of their age ‡.

In the western Salt Range the Carboniferous rocks are largely developed and highly fossiliferous. The fossils have formed the subject of former communications to this Society §, and Dr. Waagen has described the most ancient known forms of Ammonites as

* Seer Bun.

† All this older portion of the Salt-Range series, below the Carboniferous, was included in the Devonian formation of Dr. Fleming's Reports (Journ. Asiat. Soc. Beng. vol. xxii. p. 239); but the Silurian fossils of group No. 4 had not then been discovered.

‡ Mr. Lydekker found in a detached block close to Hassan Abdál (see map) a single specimen of *Productus Humboldtii*, common in the Salt Range, and also recorded from Kashmír. After considerable search I was unable to find any trace of these rocks *in situ*; and the presence of the fossil is suggestive that the Sír-Ban beds are different from the Carboniferous rocks whence this detached block came.

§ Quart. Journ. Geol. Soc. vol. ix. p. 189, vol. xviii. p. 25, and vol. xix. p. 1.

occurring in these rocks*. The formation is largely made up of limestones of varying texture and colour, not unfrequently dolomitic. Sandstones and shales occur chiefly in the highest and lowest portions, but may be found fugitively on any horizon, and the shales are sometimes coaly. There are irregularities in the surfaces of some of the upper beds, pockets in these being occupied by hæmatites, as observed by Dr. Waagen, and some of the newer beds are wanting in westerly directions. I have never found these appearances amount to actual unconformity, and the lowest beds of the formation rest quite conformably upon group No. 6.

For fuller information concerning another Carboniferous group, forming four large inliers of limestone in the Jamú (Jumoo) country, I must refer to vol. ix. of the 'Records of the Geological Survey of India.' These exposures seem to be intermediate, or else more nearly connected with the Himalayan than the extra-Himalayan system. The rocks include dense crypto-crystalline limestone, often thin and cherty, in one exposure nearest the Pír-Panjal range, massive below, less cherty and more blue in colour above, and having a banded structure like that of the Carboniferous Limestone in the Kashmír valley.

Occasional bands of siliceous flagstone and slate are intercalated, and the rocks are usually unfossiliferous; but one fragment of *Fenestella* was observed by Mr. Lydekker. The relation of these Carboniferous beds to the overlying Nummulitic group is that of complete parallelism, if not of complete conformity as well.

The largest of these exposures is exactly in the strike of the nearest half of the Salt Range. In the parallelism of its beds to the newer rocks it presents the same feature so prominent in that range and so conspicuous in its eastern part; but the Mesozoic groups are wanting, though believed to be represented along the adjacent outer flank of the Pír-Panjal range.

11. Considering the conformity mentioned between the Carboniferous formation and the beds both above and below, also the conformity between the Triassic and infra-Triassic of Hazára, and the general positions of the rocks with regard to locality, it is possible that the Carboniferous beds of Jamú and of the Salt Range, the Palæozoic groups 5 and 6 below the latter, and the infra-Triassic group of Hazára (No. 8) may all belong to one series, irregularly distributed, partly in consequence of the post-Silurian break previously noticed.

12. It appears from the descriptions of the Jamú Carboniferous inliers that the disturbance manifested is of the same character, though sometimes even greater than that shown by the arrangement of the Sír-Ban beds; that is to say, normal anticlinal flexure with the long side presented towards, and the steep side turned away from the higher ranges, or this steep side removed by denudation and fracture. In the eastern Salt Range, amongst several complexities produced by dislocation, there are tendencies to the

* Mem. Geol. Surv. Ind. vol. ix. pt. 2. A large collection of the Carboniferous fossils of the Salt Range is in Dr. Waagen's hands for examination.

same results of disturbance. In the west Salt Range, where the Carboniferous rocks occur, the general arrangement is that of a much dislocated monoclinal, or portion of an anticlinal curvature; the gentle slope towards the Himalayan area, the opposite one wanting to complete the curve. In detail the Carboniferous limestones of this ground present more closely compressed contortions than elsewhere towards the middle of the range. The forms of disturbance noticed here are common along the southern side of the whole Himalayan region, the steeper dips being away from the range*.

A westerly exposure of the Carboniferous beds is known to occur south of the Shín-ghur† mountains, and another flanking the Kaffir-Kôt hills to the southward. I have also lately received several Carboniferous fossils collected in the district of Dera-Ishmail-Khan, still further southward and beyond the Indus.

13. The ante-Himalayan series of the country between the rivers Jhelum and Indus has as yet afforded no certain information as to the conditions of the period. In the Jamú area limestones with singularly few organic traces were being formed, and occasionally fine detrital sediments were deposited. In Kashmír the basal relations of the Carboniferous beds are obscured by metamorphism—quartzites, slates, and hornblendic slates being found in this position, according to Major Godwin-Austen; while I have seen large developments of the peculiar Kashmír trappoid, amygdaloidal, or other rocks of strongly igneous aspect at the foot of the mountains (lying north-east of that valley), along which, he says, the Carboniferous formation can be traced. In the glen of the Liddur, too, among these mountains, I obtained from shaly and slaty rocks of the Carboniferous formation a few fossils, including a *Fenestella* and many parts of small Trilobites‡.

In my former paper I pointed out that these Kashmír Carboniferous deposits were entirely unlike any of the shaly bands in the Salt-Range Carboniferous rocks. As to the argillaceous beds, quantity and cleavage are the most noticeable points of distinction; the limestones, too, have a rather darker look in Kashmír (so far as I could follow them); but the waters in which they were precipitated were probably united from one region to the other, as fossils of the same species occur in both localities.

Mesozoic. *Triassic.*

14. I have already mentioned the infra-Triassic group of Sír-Ban mountain; it is composed of red shales, sandstones, and red quartzitic dolomites below, with lighter-coloured siliceous thick dolomites above, overlain by hæmatites, quartz-breccias, sandstones, and shales. The same waters in which these were deposited also laid down Triassic rocks at a later period.

* According to Mr. Medlicott, "Geology of Kumaun and Garhwal," N.W. Provinces Gazetteer.

† Sheenghur.

‡ Scarcely determinable, as Dr. Stoliczka thought, and therefore not preserved.

Limestones form the largest part of these Triassic deposits over the northern outer Himalayan area; dolomites or dolomitic beds are common, and earthy or sandy layers very subordinate, the whole forming a series of great thickness.

At Sír Ban, conformably succeeding the infra-Triassic siliceous dolomites and quartz-breccias &c., are other dolomites with quartz laminæ, dark and paler, thin, hard limestones, and towards the top of the group slaty shale and sandstones*. In these beds there are numerous Triassic fossils, among them, in the lower part, *Dicerocardium* and *Megalodon*, higher up *Nerinæa* &c. I have found in another part of the district, also (near Hassan Abdál), *Dicerocardium*-limestone resting directly on the tilted edges of the slates without the intervention of the infra-Triassic group. It is one of the most marked rocks in the northern series, crowded with sections of the fossils. Masses of thin-bedded limestone, more like that with *Nerinæa* at Sír Ban, and containing here and there small Gastropods and Echinoderms, are seen in nearly all the other exposures of the Mesozoic rocks marked on this northern part of the map.

Amongst such thin-bedded limestones south-west from Hassan Abdál I found a bed of limestone conglomerate enclosing rounded lumps of a yellowish limestone with corals, showing that denudation of some adjacent limestone tract was then going on, probably connected with the elevation which produced the unconformity at Sír Ban and Hassan Abdál.

Other representatives of these Himalayan Triassic beds, or at least rocks provisionally so considered, occur in the Kashmír territory on the flanks of the Kyjenâg and Pír-Panjal mountains; they consist of limestones and red and green magnesian schists underlying highly metamorphic slates and quartzites. All are usually quite unfossiliferous. I have only seen these rocks near Urí (Ooree) on the upper Jhelum or Vedusta river. I could find nothing definitely organic amongst them except some little Gastropod-sections in slabs which I obtained from the north side of the river. I thought at the time from their position that they represented the Nummulitic group of the northern edge of the Ráwal Pindí plateau, and observed a strong resemblance, in some of the limestones, to the Triassic beds of the hills near Murree, to which formation they have since been doubtfully referred.

Between the Jhelum and the Indus I know of no similar association of metamorphic rocks with and overlying the Trias. As here, the Carboniferous group is equally absent at the base of the *Dicerocardium*-limestone of Hassan Abdál; and if these be really Triassic rocks at Ooree, and not some of the Kiol limestones &c. of Silurian age, complete inversion may account for their position†.

* "Geology of Mount Sír Ban," Waagen and Wynne, Mems. Geol. Surv. Ind. vol. ix. p. 331. This hill presents an epitome of much of the geology of the local Himalayan area.

† As suggested by Mr. Lydekker, Pír-Panjál paper, cited above. The superposition of metamorphic upon unmetamorphosed rocks has been widely observed in the Himalayan mountains (see Memoirs Geol. Surv. Ind. vol. iii. and vol. xi. pt. 1).

In the Salt Range there is no break between the Carboniferous and Triassic formations. The same sea which deposited the last Carboniferous beds seems also to have uninterruptedly continued the deposition of the grey gypseous shales and limestones, often crowded with *Ceratites,* which there form the Triassic group. *Ceratites* and *Goniatites*, but of different species, are prominent in both. In the eastern part of the range a set of red earthy and sandstone rocks, remarkable for the prevalence of pseudomorphic crystals of salt as casts in the material of flaggy ripple-marked layers, appears to have occupied a local or isolated depositing-area of this period.

Here again there is evidence in the western part of the range, where the fossiliferous Triassic rocks occur, that the now Triassic sea received shore-deposits from no very great distance. Dr. Waagen has noted a huge block-conglomerate in these beds ; and the character of the adjacent land seems to have changed, it may have been, from prolonged elevation ; for though crystalline rocks are still found among the transported fragments, these are mostly of limestone. To the east, however, the old crystalline rocks were being more largely eroded ; conglomerates of their débris occur among the red-salt pseudomorph beds, and in one case an abrupt mass of these crystalline pebbles was observed to cross some of the flaggy layers, enclosing broken fragments of the latter, as if torrents had occasionally found their way into this basin and swept down river-shingle mixed with harder portions of the local rocks. If this was the case, the old crystalline land must have been situated somewhere near the locality*.

Jurassic.

15. Time passed, and in the Salt-Range area the same seas deposited in parallel layers a mixed and variegated series of Jurassic shales, sandstones, marly limestones, golden oolite†, and occasionally conglomeratic beds. These rocks indicate shallow-water conditions, and ripple-marks show the frequent presence of currents. Many forms of marine life existed; Belemnites and fragments of Ammonites have been found, and Dr. Fleming has recorded the occurrence of the bones and teeth of Saurians‡. He was also of opinion that some of the beds were of freshwater origin, and mentions the occurrence of ferns§ on two horizons, with lignite or jet, exhibiting the structure of the wood of Coniferæ or Cycadaceæ. If these beds were not of actually freshwater origin, land probably was not far off.

In the eastern part of the range these Jurassic beds have not been

* This observation was made on the turnpike road, near the top of the hill, over the Mayo Salt-mines, Salt Range.

† The grains coated with a shining golden ferruginous film. A similar rock occurs in the Jurassic beds of Kutch, and in continental Europe.

‡ Report on Salt Range, Journ. Asiat. Soc. Beng. 1853, vol. xxii. p. 269, &c.

§ Probably *Pecopteris.*

found; but there are rocks in about the same position thought to be of a newer age.

In the Himalayan area to the north the Jurassic formation is less clear in its relation to the Trias; in some places the succession seems to be as unbroken as in the Salt Range, in others there is unconformity of a local character, not very strongly marked, as at Sír Ban, and in others still the most prominent layers of the group are absent.

At the locality last mentioned, and in the hills north of Murree, some black (Spiti) shales, containing numerous *Ammonites*, *Belemnites*, *Inocerami*, &c., occur, which have not been met with elsewhere in this district, and a hard ferruginous and very siliceous sandstone (Gieumal sandstone?) closes the series. The greater disturbance in this northern region adds to the obscurity of the relations; and in one instance north-west from Ráwal Pindí all the rocks, though apparently conformable, are completely inverted, the Jurassic beds resting for a considerable distance at low angles on the Eocene rocks.

The most characteristic zone of the northern Jurassics is a dark limestone band rendered rough by coarse grains of quartz, and sometimes overlying more earthy beds with *Belemnites*, *Gryphœæ*, and broken Ammonites. This limestone is crowded with large specimens of *Trigonia ventricosa**, the matted red or yellow sections of which show plainly in the rock. Sometimes *Trigonia costata* and very large oysters are also present.

The Jurassic group is unknown in the border region of the Himalaya along the Kashmír mountains, nor have these rocks been found between the Upper Punjáb and Kashgar along the routes traversed by Dr. Stoliczka. Their local distribution and partial unconformity, together with their limited thickness, would seem to suggest the idea of a limit of deposition in northerly and north-easterly directions.

It is curious to observe that at the time of the deposition of the northern beds similar conditions probably prevailed here, in South India, and in South Africa, as shown by the occurrence of at least one fossil, *Trigonia ventricosa*, while in the intermediate Salt-Range region this form has not, so far as I know, been met with.

Cretaceous.

16. Nothwithstanding the local interruption at the base of the Jurassic series in the Sír-Ban section, the deposition of the sea in which the Triassic rocks were formed went on continuously elsewhere, over both Himalayan and extra-Himalayan regions, and, after the Jurassic rocks were deposited, successively laid down beds belonging to the Cretaceous period. These last present considerable variety as to thickness, composition, and organic remains.

In the Himalayan region rusty, sandy limestone of inconsiderable

* For the determination which confirmed the conjecture that this was the fossil named, I am indebted to Dr. O. Feistmantel, Geol. Surv. Ind.

thickness, but containing many fossils, chiefly Cephalopoda, immediately succeeds the Jurassic "Spiti Shales" at Sír Ban, and is overlain by pale, thin-bedded, unfossiliferous limestone. For a long distance westward this upper zone has not been identified; but the sandy limestone with its Cephalopoda reappears close to Kohát. Between this place and Attock, at Mirkulán Pass, grey limestone, associated with old-looking slates and quartzites, contains among obscure traces of other fossils some sections of Encrinite stems, which Dr. Waagen thought possibly belonged to Cretaceous species.

In many places south and eastward of Attock there is no visible representative of the Cretaceous formation between the Trias or Jura and the Nummulitic group; while the general appearance of this Mirkulán section, with its hard, old, metamorphic-looking limestones and quartzites and splintery slates, recalls the description of Mr. Lydekker's "Kiol* Series," or the association of limestones and metamorphic rocks at Ooree in the Kashmír territory.

In the extra-Himalayan area the Cretaceous group had a similarly partial development to that which it exhibits to the north. At the Chichállí† Pass near Kálabág the thin-bedded Jurassic limestones, with large planulate Ammonites, and the variegated series are succeeded by a mass of blackish-green, glauconitic-looking shales, the lowest part of which appears to have been deposited in the Jurassic period, while the upper portion of the bed contains numbers of Neocomian globose Ammonites ‡ and uncanaliculate Belemnites. These shales are overlain by a thick band of yellow sandstone, the uneven upper surface of which seems to have been somewhat denuded before the succeeding Tertiary rocks were deposited. Another indication of unconformity (apparently very local) was noticed by Dr. Waagen further down in what seems to be the same series nearer to Kálabág.

Nothing has been observed to show that there were Cretaceous deposits succeeding the Jurassic beds in the western part of the cis-Indus Salt Range; but in its central portion, conformably interposed between the Nummulitic and Carboniferous or other groups, are some impure limestones, shales, and marls, or sandy layers, containing, amongst other fossils thought to be Cretaceous §, *Terebratula Flemingii*, the distinctness of which from any known Carboniferous form has been pointed out by Mr. Davidson ||.

Further to the east a larger group of greenish sandstones and dark Boulder-clays, forming one of the upper members of the conformable series of the range, just beneath the Eocene rocks, contains occasionally some obscure casts of large bivalves. This group has been provisionally considered to represent the Cretaceous beds of other localities. It is chiefly remarkable for almost closing the list of evidences which the Salt-Range series furnishes of previously existing land to the south, by a striking example of the Boulder-

* Paper on the Pír Panjal cited above.

† Chichállee.

‡ Found by Dr. Waagen and myself together, and recognized as Neocomian by him.

§ By Dr. Waagen.

|| Quart. Journ. Geol. Soc., Feb. 1862, vol. xviii. p. 26.

deposits formed of crystalline rocks derived from unknown sources, but nevertheless from shores which probably lay to the southward. A resemblance has been thought by Mr. Theobald to exist between this dark earthy Boulder-bed and the Talchír* deposits of peninsular India; it is certainly like the description of the Talchír bed given by Mr. Fedden†, and the similarity is increased by the discovery a few months since of a red granitic boulder showing plainly polished and striated surfaces exactly such as are produced by the agency of ice. This boulder was found by Mr. Theobald on the eastern plateau of the Salt Range, among other crystalline débris, all of which seemed to have come from the adjacent dark Boulder-clay of this greenish or olive sandstone group, supposed to be of Cretaceous age. The only doubt regarding its ice-scratched appearance is whether this was produced before or after it was enclosed in the Boulder-bed near which it was found; and in the absence of decided recent glacial indications in the vicinity, such as striæ or moraines, the presumption is that the scratching of the block took place before it was imbedded in the neighbouring shale conglomerate.

CAINOZOIC. *Nummulitic.*

17. In early Eocene times there appears to have been much localization of the deposits over the whole area under notice. In the Salt Range they succeed, often with the utmost appearance of transition and conformity, the supposed Cretaceous rocks of the east and central part of the range, and also in the same manner follow those of Jurassic age to the west, with the exception just now indicated when referring to the Chichállí Pass and neighbourhood of Kálabág. In this pass, the inclinations of the Tertiary and Cretaceous junction layers are uniform, but the latter have an uneven upper surface.

To the northward, between this place and Koháts, the base of the Nummulitic series is not seen, or else that position is occupied by the great rock-salt and gypsum group of the locality (described in 'Memoirs Geological Survey of India,' vol. xi. pt. 2).

In the outer Himalayan country the basal relations of the Nummulitic beds are obscured by disturbance. At some places the succession to the next older rocks seems to be one of regular conformity; at others, though the stratification is too much disturbed to permit the relations to be seen, it is evident that the series occurring at the junction elsewhere is not present.

In the Jamú Hills the same complete parallelism as occurs at the Salt Range at the base of the formation marks its contact with the Carboniferous rocks; but the Eocene beds of this country present links both with the upper and lower beds of other places, though they do not appear to exactly represent either part of the series, the large developments of limestone having thinned away.

The bulk of the Eocene rocks are mainly limestones. The

* Talcheer.

† Records Geol. Surv. Ind. vol. viii. p. 16.

Nummulitic formation of the Salt Range is chiefly made up of these, including a band of gypseous and coaly shales. Limestones and, locally, some sandy or earthy beds reappear trans-Indus, west of the Ráwal-Pindí plateau, conformably overlying the great gypsum and rock-salt deposits. In the outer Himalayan hills the beds are darker limestones and frequently thick shales (with one instance of a lenticular coal-bed), while in the narrow outer transitional zone, separated from these by the line of abnormal contact alluded to in my former paper, the Nummulitic rocks are white or light-coloured or marly limestones, often crowded with *Nummulites* and alternating with red, purple, or greenish clays associated with masses of gypsum and beds of sandstone.

This outer zone extends from near Kohát almost to the river Jhelum and reappears at Mozufferabad; its general position in the series is clearly shown by its intercalation with the overlying Tertiary sandstones, &c.: hence it must be newer than the limestones, which do not present this transition. It is this zone which reappears in the Jamú country, associated with coaly shales and with a larger amount of clays than to the north-west. It is again feebly represented in the Eastern Salt Range, resting upon the local Nummulitic limestone, and occurs also in the same position at the north side of Khairee-Murut ridge, extending to the westward and forming the lower part of that elevation west by south from Ráwal Pindí. From the presence of the gypsum in this upper Nummulitic band, and transitional appearances here and there to the west, it is not improbable that the trans-Indus Nummulitic limestone may be a local development of the upper part of these rocks.

The upper Nummulitic band does not appear as a continuous belt along the outer flanks of the Pír Panjal and other high ranges of Kashmír in the same relative position which it occupies in the Ráwal-Pindí district, a result apparently due to dislocation. It also appears to have changed its character, becoming greyer and redder, and containing less limestone, in its extreme north-westerly exposure among the hills south of the Pesháwur valley.

18. The conditions of this Eocene period must have varied considerably over the upper Punjáb. In the northern direction the dark limestones and fine clays would correspond with the existence of deep seas, in which the greatest thickness of these rocks was deposited; the Foraminifera and other organisms, too, are minute and often scarce. In the Salt Range, on the contrary, fossils are abundant, such as Nummulites, large Lucinidæ, and Gastropods and Echinoderms of large size, occurring in pale, often nearly white, limestones, probably here deposited by clearer water. At or near the base of the most eastern part of the exposure, highly ferruginous mud associated with pure white clay was precipitated, and now forms a hæmatitic band (or bands) which has also been identified in the Jamú Upper Nummulitic zone, showing that the more massive limestones have thinned away to the east.

In the Salt Range, at about the same horizon, are beds of white sandstone and grey or red shale, while along the whole range dark coaly or black alum-shales with inconstant bands of hæmatite are found, generally near the base of the group, but with some exceptions. In the eastern half of the range the coal-shales, containing one or a divided bed of coal three feet or less in thickness, lie very near the base of the group; further west there is nearly as much Nummulitic limestone below as there is above them; while south of Sakesar Peak and near Kálabág the alum shales among the lower beds occur on two or three horizons. This irregularity along the southern base of the Eocene deposits, and the fact of their entire absence at places about the east end of the Salt Range, as well as in some localities trans-Indus, coincides with the local character of the whole of these Nummulitic deposits.

The smaller developments of limestone in the trans-Indus Salt region and along the northern margin of the Ráwal-Pindí plateau approximate in general character and in abundance of organisms. In the former region exceptional conditions must have prevailed to have produced the great saline and gypseous group of that district; but there is as little to show what these were as there is in the case of the Salt-Range saline series.

The Eocene (?) trans-Indus salt is of a different colour from that of the Salt Range; it is uniformly grey, rarely so massive, often showing its stratification more strongly, owing to numerous partings of greenish clay between the beds, and much more frequently presents a blotched appearance from the occurrence of pure crystalline lumps in a more earthy or crypto-crystalline matrix. It shows at Bahadur Kheyl an apparent thickness of from 1000 to 1230 feet, more than double that of all the salt-beds at the Mayo mines in the Salt Range, or more than equal to the whole salt-marl, salt, and gypsum as exposed at the latter locality. In other places the thickness as seen is not nearly so great, but nothing below the salt, is anywhere exposed. The gypsum in this case also overlies the salt; petroleum impregnates both, and there are no volcanic rocks in association to suggest any means of accounting for the peculiarities of the conditions under which the salt and gypsum were accumulated. As to disturbance, these beds have yielded to force quite in the same way as any other stratified rocks. It is not easy to give a close estimate of quantity from the varied nature of the exposures; but a rough one has been attempted, and on the supposition that the areas in which salt is pretty certain to occur would together make up five square miles, with an average thickness of only 200 feet, the amount of salt present would be over 1500 millions of tons, sufficient, after making a large allowance for waste*, to last at the present rate of consumption for over 40,000 years.

The Nummulitic zone bordering the northern hills, in its mixture of limestones, clays, and sandstones, has more the character of an offshore deposit than any of the apparently older and more exclu-

* On exposed surfaces this salt is, of course, very liable to waste from solution. It is roughly estimated that 450,000 cubic feet are annually dissolved and removed in this way. Mem. Trans-Indus Salt Region, cited above, Appendix, p. 221.

sively limestone accumulations of the Upper Punjáb Eocene period; but it is not until the hills south of the Pesháwur valley are reached that thin layers of conglomerate are found in these beds.

Gradual and local changes of level in the Eocene area surrounding the Ráwal-Pindí plateau appear to be the most probable causes for the local and fluctuating character of these Nummulitic deposits. The outer part of the hill region to the north would seem, at all events, to have been at one part of the Eocene period deeply submerged, and again to have received in shallower water the mechanically formed sediments from some adjacent land, probably situated towards the Himalayan area. Land also seems to have existed near the Salt Range, whence the vegetation to form its coal-beds was derived. Towards the close of the Nummulitic limestone period in the last-named region, from the occurrence of some conglomeratic layers at the top of the group made up of flints and fragments of the limestone itself, a portion of these rocks must have been brought within reach of denudation, though no disturbance sufficient to produce discordance where the conglomerates are found took place.

Slight elevations such as this may have been the commencement of the grander actions of the same kind which subsequently occurred.

Tertiary Sandstones and Clay Series.

19. The rocks of this series occupy by far the largest area of the district under notice, forming nearly the whole of both the Ráwal-Pindí plateau and the hilly outer Himalayan tract of Jamú-Kashmír. They have also the greatest stratigraphical thickness of any of the better-known formations, amounting in the aggregate, upon a reduced estimate, to between four and five miles!

I have already described these rocks in a former paper to the Society, and need only say that their monotony of character enables a sufficiently clear general idea of them to be conveyed in a few words.

The lowest beds, which intercalate with the Nummulitic rocks along the outer edge of the northern hill country, are purple and grey sandstones and red and purple clays, forming the Murree group. Succeeding to these are grey (Siwalik) sandstones and red clays, the red colour of the latter gradually giving place upwards to brown and orange; and the sandstones, after becoming conglomeratic, change into strong conglomerates of hard rounded crystalline pebbles, derived from the waste of Himalayan rocks. Mammalian and reptilian remains occur throughout, even occasionally in the Nummulitic beds below*, but are rarely of much palæontological value, except in the Lower Siwalik subdivision, where the largest numbers and most unique forms have been found.

The groups which I formerly described† are now thus classified, in descending or natural order:—

* Records Geol. Surv. Ind. vol. ix. p. 87.
† Quart. Journ. Geol. Soc. vol. xxx. pp. 66, 67.

Upper part of group D = Upper Siwalik, Conglomerates.
Groups B, C, and lower
part of D . . . . = Lower Siwalik, Sandstone and clay.
Groups A and E . . . . = Murree Beds, Sandstone and clay.

These rock groups exhibit throughout marked conformity of superposition and, from their intercalation with the underlying Eocene rocks, of course complete conformity with them also, so far as parallelism of stratification is concerned. Oblique lamination and current-marks occur, but the beds present no structural peculiarity to indicate that they were always accumulated at steep angles of deposition, or formed banks with sufficiently distinct irregularity of shape and thickness to become evident or prominent in the stratigraphic aspect of the series. Nor is there any thing to mark the place at which the marine conditions of the Eocene period become changed into freshwater ones at later times. Although very large land and partly aquatic animals, with many smaller ones, have left their remains more or less generally distributed, it is only near the upper limits of the Lower Siwalik groups that I have found fossil freshwater shells (Unionidæ).

It has been observed of other regions south of the middle part of the Himalaya Mountains*, that it is not to be supposed the whole thickness of the Tertiary sandstones &c. was ever strictly superposed vertically, but rather that these deposits (or the newer ones at least) were laid down bankwise, each overlapping an older bank and extending beyond its lateral limits in one direction, the deposition taking place contemporaneously with a gradual elevation on the side from which the materials come.

In attempting to apply this mode of deposition to the ground under notice it will be seen that the newer rocks are distributed in a zone having some parallelism to the contour of the hills, but situated nearer to the Salt Range than to the Himalayan area. This arrangement of the newer zone is due partly to the smaller thickness of the Murree beds southwards, and partly to the more intense folding and disturbance of that older group in the other direction, which would cause them to occupy more ground.

Whether this greater intensity of disturbance was actually taking place, accompanied by elevation, during the deposition of the Siwalik beds, there is little to show. Still a few scattered pebbles of hard Murree sandstone and of Nummulitic limestones, occurring in conglomeratic beds among the Siwalik strata, on different horizons, afford some indication that both to the north and south of the Pindí plateau (probably at a considerable distance) these older rocks had been elevated sufficiently to undergo denudation beyond the limits of the depositing area of which the plateau then formed a part.

It may be that the whole of the detrital Tertiary rocks were

* Memoir on Kumaun and Garhwal, in the North-Western Provinces Gazetteer (India).

deposited in the banked or lateral manner mentioned above, and that their deposition was concurrent with slow elevation of the Himalayan and Salt-Range regions, probably greater in the former. If so, the deposits would be perhaps thickest near their sources, slightly different in each direction, and their quantity would be some measure of the watershed areas undergoing denudation.

This supposition would coincide with the greater amount of the older (Murree) beds on the Himalayan side than to the south, and with a difference observable in their lithological character; but the observation cannot be extended to the newer portions of the plateau series, their thinning out constantly in any particular direction not being evident.

It is plain that the materials of the conglomerates in the newer beds came from the Himalayas, and were brought down by rivers following the same courses as the Jhelum, the Indus, and the Kúram (Koorum) do now. These coarse pebble- and boulder-beds change greatly both in thickness and in composition, becoming finer and associated with a greater quantity of clays in the interval between the two first-named rivers, away from where the pebbles were being supplied. Hence the antiquity of these great channels of drainage may be inferred, and it is interesting to observe that we have one of the structural features of the Simla outer Himalayan belt represented here*.

20. The local conditions of this period, extending from Eocene to Pliocene times, present a great contrast to those previously noticed. Hitherto the organic remains would show that through all the preceding geological periods the deposits may have been principally marine! But now, from the transitional upper limits of the Nummulitic deposits to the top of the Tertiary series, the rocks contain, so far as I am aware, only the remains of terrestrial or freshwater animals. Some of these would indicate a swampy or marshy habitat, such as Dr. Verchère has suggested†; but others, such as the horse, camel, &c., would appear to have required dry uplands, and others still, like the elephant, forest-lands as their residence. I have found no trace of an old land surface, even though it were a swamp like the Tarai (at the foot of the Himalaya), among the Tertiary beds, all of which appear to me to have been laid down in open water, nor yet any adequate fossil representatives of former forests or the smaller vegetation necessary to support these animals; I am therefore obliged to conclude with Mr. H. F. Blanford, that the waste of the mountains was poured out into a lake or sea, and possibly an inland sea‡.

Although one can scarcely consider them the remains of forests, blocks of siliceous fossil (exogenous) trees are found among the older or "Murree beds" on each side of the Ráwal-Pindí plateau, but in the greatest numbers on the north flank of the Salt Range (Mt. Tilla &c.) and trans-Indus; portions of carbonized trees have

* Mem. Geol. Surv. Ind. vol. iii. pt. 2.
† Journ. As. Soc. Beng. vol. xxxvi. 1866–67.
‡ Blanford's 'Physical Geography (India),' p. 131.

been also found near the Jhelum, and in a few other places among the next newer beds (Lower Siwalik). The localities of the greater quantities of the first-mentioned fossil wood may indicate the existence, at an early part of the period during which the detrital beds were formed, of a considerable land area to the south and south-west of the plateau; while the newer carbonized trees would show that land, whether it was forest-land or not, existed in the vicinity later on, though probably not actually within the ground now occupied by the Siwalik rocks.

It is to the close of this great Tertiary period that the disturbance which produced the neighbouring parts of the Himalayan and the Salt-Range mountains is usually referred. The whole geological series, up to the newest Tertiary deposits, have undergone lateral compression with contortion, and the general conformity of all in the Salt-Range region shows that this contortion must date from a period succeeding that of the most recent of the disturbed rocks.

Minor disturbances may have influenced the distribution and given the local character to many of the formations, but did not produce the folding or bending which affects the whole.

In the northern part of the district, however, one can go further and say that previous disturbance and elevation had taken place, causing a marked break between the Silurian and Triassic periods; the Triassic and infra-Triassic rocks, though themselves partaking of the more recently communicated inclination and curvature, were deposited upon the upturned and denuded edges of the slates*.

Over that part of the frontier country which includes the trans-Indus salt region, the effects of the more recent disturbance have been intensely marked; this is probably owing to the yielding or softer nature of the gypsum and earthy beds associated with the salt now occupying the interiors of anticlinal ellipsoids of hard Nummulitic limestone and Murree beds. These anticlinals are so compressed and disturbed at points below the denuded crowns of the arches that inversion is the rule and not the exception.

The part of the Ráwal-Pindí plateau lying south of the Sván River is the least disturbed area in the whole district, this valley coinciding with a large open synclinal hollow, within which rest the higher beds of the Tertiary series.

Faults connected with the same disturbance are prevalent in many parts of the country, in the Salt Range, trans-Indus, and along the northern side of the Pindí plateau, particularly in the vicinity of the abnormal junction between the older Tertiary sandstones and the limestone rocks of the outer Himalayan hills.

* I can find no record of a similar unconformity or disturbance of the slates &c. in the Simla area before the deposition of the supposed Triassic Krôl beds. Hence if the Krôl be Trias, and conformable to the rocks below, there must have been local disturbance and elevation in this region of the Himalayan chain while the Krôl portion of the Simla area was yet undisturbed Triassic (or perhaps older) sea-bottom.

Post-Tertiary.

21. A long interval of time, during which the whole surface of this area underwent enormous changes as to form, followed the latest Tertiary period on record. At the close of that period there were tranquil waters, inhabited by crocodiles and tortoises &c., depositing masses of fine saline silt upon the shore-like shingle brought down from the Himalayan region. Then these great mountains and the Salt Range were formed, or still further elevated, and the general level of the country where the Ráwal-Pindí plateau is now situated may have stood more than 2000 feet higher than it does at present. This elevated region, too, may have been limited to the south of the Salt Range by as definite a boundary as that of any part of the southern face of the Himalayan region to the eastward.

Much, if not the whole, of the plateau and its vicinity was again covered with water after it had received its present general form, and into this water, gulf, or lake-basin the great Himálayan rivers continued to bring down much the same kind of mountain detritus as they had done before; beds of conglomerate were deposited and banked up at tolerably steep angles in places. These occur even on such lofty situations as now form the top of the Salt Range and mountain tops 2000 feet above the present bed of the Indus, south of Attock. On these elevations, and near Kálabág, the well-rounded crystalline pebbles are of the same kinds as those which the river beneath still carries from its Himalayan regions.

Besides showing the continuons denudation of some high lands in the Western Himalayan region, the later pebble-beds of this period bring the scene of that denudation nearer to the present district, perhaps within it; for the detritus, though still largely consisting of quartzite, contains as well masses of limestone pebbles derived from the waste of the Triassic and other limestones of this outer Himalayan area immediately to the north.

In the Ráwal-Pindí plateau the pebble-beds, of quartzite and limestone chiefly, are covered by thick horizontal beds of silt; beyond the first ridge to the north (the Chéta range) gravels, formed mostly of syenitic débris, are also horizontally overlain by coarse grey sand in massive beds, enclosing large subangular fragments of similar crystalline rocks. This variety in the deposits would indicate that the waters of the time lay in different basins or gulfs, and received the drainage of different areas undergoing denudation.

Changes of level, as well as previous denudation of the ground, may very possibly have been connected with the distribution of these post-Tertiary deposits, and some of the coarser accumulations may now remain where they were deposited by rivers; change of climate, too, might have occurred. From this or other causes the terrestrial fauna of the Siwalik times seems to have almost entirely disappeared from this neighbourhood, as well as all traces of arborescent vegetation, though the calcareous cement of certain of the pebble-beds locally present may have been partly due to the existence of some kind of vegetable matter.

I have heard of one elephantine bone being found in the Soán post-Tertiary conglomerates, and another bone, "probably of a camel," is recorded by Major Vicary in the detrital deposits of the Pesháwur valley between Attock and Nowshera; but I have only seen a single bone fragment in the rocks of this period, near the junction of the Haró river with the Indus. The finer silts of the Ráwal-Pindí plateau contain numerous small land and freshwater shells of recent species.

Erratics.

22. Lying upon or partially buried in the old alluvium, loess, or silt of the post-Tertiary deposits there are, somewhat locally distributed along the left side of the Indus from Attock southwards, groups of erratic blocks frequently of very large size, and I have heard of their occurrence also on the north side of the Pesháwur valley.

Dr. Verchère was, I believe, the first to notice these, and to attribute their transport to the agency of floating ice. They lie between 33° 5′ and 33° 50′ N. lat., and are nearly always formed of crystalline or igneous rocks, their Himalayan origin being indicated by the occurrence amongst them of the porphyritic gneiss of the Kyjenâg range and Hazára: some of them have girths of 50 feet, and one which I measured is 17 feet high. Another, of white granitic rock, near it gave the following measurements:—Girth 50 feet, length 14 feet, width 9 feet, height 6 to 8 feet, from which its calculated weight comes to between 75 and 80 tons.

One way of accounting for the occurrence of erratics such as these is by the supposition* of great quantities of detritus filling up the valleys in which they lie, and forming a steep talus from the parent rock, down which they might have been impelled by diluvial action. Another is the exertion of intermittent torrential energy, as held by Mr. J. F. Campbell† with regard to the Himalayan erratics of the Kangra valley In the present case neither of these methods seems to be applicable. The erratics under notice are just as angular or as much rounded as exposed masses of the rock *in situ* might be under the influence of atmospheric agencies, agencies which would in most instances have long since obliterated scored and polished surfaces. They are associated with the valley of the Indus by their distribution within ten miles or so of that river; but the distances to which they have been carried from the high ranges where such crystalline and igneous rocks exist, at least 100 miles to the north, would scarcely admit of a steep surface inclination for a supposed talus with the least probability.

* Advanced by Mr. Medlicott with regard to the erratics of the Daulahdár range in the country below. "Geology of Kumaun and Garhwal," North-Western Provinces Gazetteer (India).

† Paper on Himalayan Glaciation and note by Mr. Medlicott, Journ. As. Soc. Beng. vol. xlvi. pt. 2, p. 1.

Torrents from the mountains, down the valley of the Indus, on reaching the waters in which the post-Tertiary silts &c. were deposited, now supporting (and sometimes partly enclosing) the erratic blocks, would expand, losing their impetus as well as their carrying power, so that the blocks should all be found collected at the exit of the river from the Attock gorge, which is not the case.

But the river Indus is well known to be subject to violent torrential floods at more or less long intervals. I find in the interesting memoranda on the Indus floods by Captains Henderson and Broadfoot, of the Royal Engineers, published by the Government of India, that destructive floods have occurred about the years 1811, 1831, 1841, and again in 1856, 1858, 1874, and one was threatening in 1875; also that these *débâcles* are attributed to the glaciers of the Gilgit and Shyôk regions giving way and slipping so as to block up narrow parts of long, but not steeply inclined valleys, at a height of about 9000 feet above sea-level and 8000 feet above Attock. This is supposed to have occurred at from 300 to 600 miles up stream above the last-named place; and Captain Henderson assumes the mean fall of the Indus and Shyôk rivers for this distance at $13\frac{1}{2}$ feet per mile, through a rocky channel as far as Torbeyla, and that of the Indus from Attock to Kálabág at 23 feet per mile*. The velocity of the flood of 1858 he calculates at 15 miles per hour from Attock to Kálabág, and more than this from the upper parts of the river to Torbeyla.

The flood deposited a fine silt, from description much resembling that of the post-Tertiary beds of the Ráwal-Pindí plateau for a foot or more in depth, over the Chutch plains and lower part of the Pesháwur valley.

I have not been able to find it recorded that floating ice has reached even as far as Attock, nor have I any personal knowledge of the large erratic blocks being found along the Indus above that place; but it can be easily conceived that under different conditions as to climate, when the general elevation of the country may have been greater than it is at present, such floods as these, with a sudden rise in the river of from 55 to 80 feet, might have washed down large fallen fragments of glaciers laden with these crystalline rock masses, the "large rough blocks of granite" which Captain Henderson observed to be important components of the Shyôk glaciers.

It is somewhat remarkable that these large erratics do not occur along that part of the Jhelum valley which is still a torrent eastward of the Ráwal-Pindí plateau. I have seen smaller crystalline (granitic) blocks some hundreds of feet above this river, several miles south of Mozufferabad, and they are of course both larger and more numerous where the river crosses the Palæozoic schists &c. higher up in the Kashmír territory. Their absence in groups along the lower part of this rapid stream may be due to the circum-

* There seems to be some error or misprint in this; the difference of elevation, 288 feet, divided by the distance, 94 miles, gives the fall of the river between these points as 3·06 feet per mile.

stance that the mountainous ground adjacent was perhaps not submerged beneath the water which deposited the post-Tertiary silt, or the glaciers of the Kashmír, Kishengunga, and Nainsook valleys may not have extended downwards, or been so large as those of the Indus valley and its tributary from Kâbul.

Besides the erratics in the neighbourhood of the Indus there are others, locally distributed, on the eastern part of the Salt Range, or scattered over the country in that direction. They are mainly composed of a red granite, the source of which is unknown; and the largest of these blocks now lying on the red salt-marl near the Mayo salt-mines at Khewra, has been estimated from measurements taken by Dr. Warth, to have a weight of about 9 tons.

From the similarity of this granite to blocks contained in the Cretaceous, or supposed Cretaceous, boulder-clays, both may have come from the same source originally, in which case the ice-scratched block found by Mr. Theobald possesses an important signification with regard to glacial action having operated upon a former land surface, the only traces of the existence of which here are the indications afforded by the foreign materials of the Salt-Range series and neighbourhood.

Recent.

23. During and since the post-Tertiary period denudation has been most actively at work forming the present features of the ground. Since some of the post-Tertiary pebble-beds were deposited the forces of denudation have lowered the hanging level of the Indus 2000 feet, and reduced the softer Tertiary ground to the lower altitude of the Ráwal-Pindí plateau. They have also cut out the deep glens among the hills around, eaten this plateau into a labyrinth of vertical-sided ravines, strewed the whole southern face of the Salt Range with great dislocated portions of its rock groups by removing the soft marl or salt beneath, and they continue to supply the bed of the Indus with the same hard Himalayan boulders which found their way downwards by the same channel in later Tertiary and post-Tertiary times.

In doing this, however, denudation has not followed, but produced the ridge-and-valley form of the ground. The principal rivers, as well as many of the minor streams, intersect the ridges and ranges in more or less directly transverse directions, showing that the general elevation of the whole country towards the Himalayan axes gave the initial direction to its drainage, the courses of which, being fixed at an early post-Tertiary or even Tertiary period, denudation has since revealed the forms which the stratigraphic structure of the ground, influenced by elevation and disturbance, induced the erosive agency to display.

Over most of the country this agency, in Recent times, has been destructively employed; but in some spots construction of calcareous tufa or deposition from rivers has been taking place, the largest deposits of the latter kind being the alluvium of the Jhelum and of the Indus, that of the former river above and below the station of Jhelum, that of the Indus only above Attock and below Kálabág.

The fan deposits described by Mr. Drew in the more lofty regions of Kashmír are represented here by local accumulations, such as the fringing deposits of the southern foot of the Salt Range and those of the higher mountains west of the Indus. They occur forming large talus deposits in the Banu (Búnoo) valley, to the south of the Shínghur (Sheengur) Mountains west of Kálabág, and around the Affrídí (Affreedee) Hills; but there are fewer and smaller traces of these fan deposits to the east, where they may be partly represented by the pebble-beds of the post-Tertiary deposits, with this difference, that to the west and south the formation of these detrital masses is still in progress.

In these Recent times vegetation again flourished where now it is comparatively scarce, large leaves of trees being found in deposits of calcareous tufa where at present brushwood only grows. But the large animals of the Siwalik times had passed away, and the conditions of the present afford a natural existence to no larger quadrupeds than the wild sheep (*Ovis cycloceros*), markhor (*Capra Falconeri*), small ravine gazelle, mountain bear, tiger, panther, wolf, fox, or jackal.

Summary.

24. From the foregoing notes it will be seen that the geological history of this part of the world extends back to very remote times, and that through nearly all the extra-Himalayan formations there are found some indications of land, probably lying to the south, even perhaps connected with the old tropical continent (Lemuria) supposed to have joined the present peninsular India with Africa as late as the Tertiary period.

In the region between this old land and that where the Himalayan elevations afterwards took place, a state of things existed at two widely-separated periods (pre-Silurian and Eocene) which resulted in the formation of enormous deposits of rock-salt, and in association with the oldest of these there are traces of volcanic energy having been displayed.

In the Himalayan area the marine deposits older than Tertiary present fewer indications of terrestrial conditions. Still that denuded land did exist in those regions, between the Silurian and Triassic ages, is shown by the unconformity at the base of the infra-Triassic rocks, and again indicated by a bed of Mesozoic limestone-conglomerate enclosing rounded lumps of coral-limestone.

In this Himalayan or Western Himalayan region it has been shown that there was again land (probably mountainous) from an early post-Eocene period, if not earlier, also that this elevated ground continued to supply detritus to be carried southwards from the Tertiary period till the present time.

As this later elevation gave the first direction to the drainage-system of which that of the region under notice forms a part, and as the river Indus is one of the drainage-channels, it would appear that the elevation was earliest or greatest in the region where the Indus, the Satlej, and the Brahmapootra rivers rise among the central portions of the Himalaya Mountains.

That glacial conditions prevailed in the Western Himalaya during the post-Tertiary period, either to a greater extent or nearer to the Ráwal-Pindí plateau than they do at present, is to be inferred from the distribution of the large erratic blocks noticed, their transport to where they now rest being attributable to flotation by ice, for want of other evidences of glacial action such as moraines or glacial striæ, to the preservation of which, however, the climatic conditions are not favourable.

It would also appear that another and an older glacial period may have affected part of the formerly existing land to the southward; this is shown by the striated boulder of a red granite, unknown in the Himalaya, found by Mr. Theobald on the Salt Range, and fairly presumable to have been enclosed among the pre-Tertiary (or Cretaceous ?) Boulder-clay of that country. Should its striation have occurred since it was removed from this boulder-bed, the glacial period would have been later, probably post-Tertiary, and would account both for the presence of such blocks as the one near Khewra, and for the distribution of the numerous small boulders of the same granite in the country near the east end of the Salt Range. It must be remembered, however, that the clay and boulder-bed whence this block is supposed to have come answers very closely to the description given of the ice-scratched boulder-bed of the Talchír* group described by Mr. Fedden†.

In connexion with the subject of this Cretaceous (?) boulder-bed it may be mentioned that such boulder-shales or clays, first found in the Talchír rocks of central peninsular India by Mr. W. T. Blanford‡, are now known to occur in other places as well. He has recently described an earthy boulder-bed near Lowo and Pokran, in the Sind desert§, older than the Jurassic beds of that country, older even than rocks supposed to be of Vindhyan, and consequently of Palæozoic age. These occur under circumstances which render it possible that they have been transported by ice; so that it appears there are different horizons, sometimes widely apart, in the Indian geological series upon which ice-borne crystalline blocks are found, usually enclosed in soft earthy deposits. Hence the very oldest of the Salt-Range Boulder-clays resting upon the salt-marl may yet be found to contain ice-scored blocks, and all may indicate a recurrence of glacial periods in India, dating from very early geological ages.

EXPLANATION OF PLATE XIV.

Sketch Map of the Geology of the Upper Punjáb. (Scale 50 miles to an inch.)

* Talcheer. Trias according to Dr. Feistmantel.
† Records Geol. Surv. Ind. vol. viii. p. 16.
‡ Memoirs Geol. Surv. Ind. vol. iii. p. 37.
§ Records Geol. Surv. India, vol. x. p. 17.

Discussion.

Prof. Ramsay was glad to find that the author endorsed his view of the recurrence of glacial epochs, which had now been advancing for several years. From South Africa there was evidence of a glacial epoch of early date, in the form of great boulder-beds lying on *roches moutonnées*, the origin of which could be traced more than 100 miles away into existing mountains. He thought that the average climates of the world had not greatly changed since the Silurian period.

Prof. T. Rupert Jones remarked that Dr. Fleming had, many years ago, published a notice of this district in the Society's 'Journal,' and that he believed some of the specimens were still in the Museum of the Society.

Prof. W. Boyd Dawkins said that although scratched boulders might prove the action of ice, the requisite climatal conditions might be attained by increased elevation of the land above the sea, so that they could furnish no proof of the occurrence of a so-called glacial period. He thought, for example, that in the Miocene period, if there had been a glacial period in Europe, it ought to have made itself felt in the fauna and flora; yet both these were tropical. The fossils of the Siwaliks were abundant, and included an immense number of vertebrates, but none that showed any thing of a northern type. Hence he thought that the scratched blocks might perfectly well have been produced by local elevations of the land.

Prof. Seeley agreed with Prof. Dawkins that for the production of what were regarded as the phenomena of a glacial period, nothing more than increased elevation was required; thus in the Permian, for example, the land might well have been elevated into mountain-chains, and thus glaciers appeared. Even at the present day, with glaciers on the Himalayas, there were tropical plants at no great distance on the plains below.

Mr. Johnston-Lavis wished to ask, if one hemisphere was in a glacial condition, where would the tropics and equator be situated, seeing that Prof. Ramsay said that he did not believe there had been much change in climate since Silurian times?

Prof. Ramsay explained that he did not use the term "glacial epoch" as equivalent to Lower Silurian, or Devonian, or Miocene; in fact it was rather a glacial episode than an epoch. He held the same opinion as Dr. Croll, that when there was a glacial epoch in the northern hemisphere there would be the reverse in the southern.

Mr. Ussher inquired whether an unconformity existed below the Triassic group.

Dr. Oldham said there was conformity all through the series in the district described by the author, but that unconformity occurred in other districts.


SKETCH MAP OF THE GEOLOGY OF THE UPPER PUNJAB
Scale 50 miles = 1 inch.
Alluvium
Upper Siwalik Conglomerates
Lower Siwalik &c
Newer Tertiary
Older Tertiary Murree & Upper Nummulitic
Limestones Nummulitic
Cainozoic
Cretaceous, Jura, & Trias
D° Limestones
Mesozoic
Carboniferous, limestones.
Silurian & older Slates, Sandstones &c Salt Range Rock-salt &c
Gneiss &c.
Palæozoic
NUNGA PURBUT 26,629
WESTERN HIMALAYA MTS
Course here unknown
BAJAOR SWAT & UMBEYLA MTS
British Frontier Line
YUSUF ZAI OR PESHAWUR VALLEY
Murdano
Kabul Riv.
River Indus
Khybur Pass
AFGHANISTAN
AFFRIDIS HILLS
Peshawar
Nowshera
Torbeyla
988
Attock
Hassan Abdal
Post Tertiary
Erratics
OUTER HIMALAYA
HAZARA
Abbottabad
Limestones
Mozufferabad
R. Vedusta
R. Jhelum
Murree 7467
Rawal Pindi 1775
OUTER HILLS
Wullar Lake
Srinuggur
VALLEY OF KASHMIR
PIR-PANJAL RANGE
11400
Shapian
Islamabad
Kohat
Erratics
KHAIRE MURUT RIDGE
ROCK SALT REGION
Soan R.
1476
RAWALPINDI PLATEAU
UPPER PUNJAB
Banu
BANU VALLEY
R. Kuram
Kalabag 700
R. Indus
Esakhail
KAFFIR KOT HILLS
THE SALT RANGE
Sakesar Pk 5010
Mayo Salt Mines
Pind Dadan Khan
R. Jhelum
M. Tilla
Jhelum 150
Northern State Railway
Gujrat
Bhimbar
JAMU HILLS
HIMALAYA
KASHMIR
Jamu
Sialkot
Basaoli
Chamba
Dalhousi
Alluvium of the Plains

21. *Note on two* SKULLS *from the* WEALDEN *and* PURBECK FORMATIONS *indicating a new* SUBGROUP *of* CROCODILIA. By J. W. HULKE, Esq., F.R.S., F.G.S. (Read February 6, 1878.)

[PLATE XV.]

AN examination of the crocodilian skull exhibited last session by Mr. Willett, and of an undescribed skull in the British Museum, No. 41,098*, has brought to light a peculiarity in the posterior nares which, so far as I am aware, had been previously recognized only in the small crocodilian skull from Brook, Isle of Wight, in the Jermyn Street Museum, described by Prof. Huxley in a paper communicated to this Society on 28th April, 1875, and figured in the Quart. Journ. Geol. Soc. vol. xxxi. pl. xix. fig. 3.

This, and the great probability of the correctness of Mr. Willett's reference of his acquisition to *Goniopholis crassidens*, the skull of which was before quite unknown, have seemed to me to invest these skulls with sufficient interest to warrant me in offering a short account of them to the Fellows.

I. *Mr. Willett's Crocodilian Skull* (Goniopholis crassidens, *Owen*?). (Pl. XV. figs. 1 & 2.)

Viewed from above, the outline of this skull has the form of a slender isosceles triangle, the base of which, taken between the extreme outer posterior angles of the quadrate bones, measures about 13 inches, and the nearly straight sides from the same points to the premaxillary suture 25 inches. The uniform convergence of the sides is broken by a slight inbend in front of the orbits, by a small outbend at the 6th, 7th, and 8th maxillary teeth, reckoned from before backwards, and by the abrupt expansion of the præmaxillæ occasioning a deep lateral notch at their union with the maxillæ.

The upper surface of the skull, behind the orbits, has a nearly oblong figure; its posterior border measures 8 inches, the anterior border $7\frac{1}{4}$ inches, and the lateral borders 5 inches. The temporal openings, of a roughly quadrilateral form, are very large; their antero-posterior diameter is $2\frac{3}{4}$ inches, and their transverse measurement $2\frac{1}{4}$ inches. The intertemporal part of the parietal bone and the postfrontal squamosal bars are very narrow.

Between the orbital openings the upper surface of the skull is transversely concave and almost plane sagittally. These openings look upwards and outwards. Their upper border is very prominent, and it has, filling a deep angular notch, wedged in between the postfrontal and prefrontal bone a distinct supraorbital ossification mesially marked off from the neighbouring bone by a sutural groove distinctly apparent on the upper and also on the under surface of

* This appears to be the specimen figured by Prof. Owen as *Goniopholis simus* in the volume of the Palæontographical Society's Memoirs issued since the present paper was written and sent in to the Geological Society.

the orbital roof. The prefrontal is small, the lachrymal large, forming the greater part of the front and adjacent lower border of the orbital opening. The nasal bones, long and moderately narrow, taper anteriorly to an acute point, and they end at two inches distance from the single undivided external nostril. The præmaxillæ extend backwards on the upper surface of the snout for nearly four inches from the external nostril, and they end here as acute wedges interposed between the nasals and maxillæ, about two inches higher in the snout than the anterior termination of the nasals. The external nostril is dilated transversely; it is wholly visible on the upper surface of the snout, not obliquely, terminally placed as in Teleosauria.

The whole of the upper surface of the skull, including the snout, the upper part of the descending bar of the postfrontal, and the expanded posterior part of the quadrato-jugal bar, is richly sculptured. Behind and between the orbits and on the first-mentioned bars the ornamentation has the form of large, more or less circular, crowded pits; in front of the orbits these are smaller and less close, and in the snout they are lengthened and assume the form of short shallow grooves grouped with some degree of parallelism to the axis of the snout. On the front of the præmaxillæ, where the surface slopes down to the alveolar border, they are nearly absent, this part being almost smooth.

The occiput has the usual crocodilian construction; but the paroccipital processes are relatively larger, they project more directly outwards, and they have a smaller backward slant than in extant crocodiles. As in *Hylæochampsa*, Owen, from the Isle of Wight Wealden clays, their outer ends project beyond a line dropped vertically from the squamosal angle of the skull.

Under surface.—The palate in the neighbourhood of the premaxillary-maxillary suture (the exact form of which is not discernible) is almost plane longitudinally and transversely. From here a broad shallow mesial groove, separated by a slight elevation from a less conspicuous longitudinal groove just inside the alveolar border, stretches backwards to opposite the 8th or 9th maxillary tooth, behind which the mesial groove is lost, the palatal surface becoming gently swollen in the neighbourhood of the palato-maxillary suture, the precise direction of which is no longer traceable. The pterygomaxillary openings are very large and long, as in the Brook skull, to which reference has been already made (see Quart. Journ. Geol. Soc. vol. xxxi. pl. xix. fig. 3), and the palatal bones form a correspondingly narrow median beam. These bones appear to end posteriorly at the middle of the palato-nares, and the pterygoids applied to their inner margins form nearly the entire lateral boundary of these openings, except for a small space just in front. In these structural respects, as also in the long narrow slit-like form of the palato-nares with slender pterygoid internarial septum, the palato-nares in this skull repeat very closely the characters of the same openings in the Brook skull, and, as in this, they approach posteriorly the mesial Eustachian orifice more closely than obtains in

Steneosaurs. The lateral and posterior portions of the pterygoids are unfortunately mutilated, so that the relations of these to the narial openings behind are not shown. The transpalatine bones have been broken off.

Teeth (fig. 2 *a*).—These are of very unequal sizes. In the maxilla they gradually enlarge from the first to the fifth or sixth, counted from before, which are stoutest; and from these they decrease more gradually towards the back of the jaw, where they were relatively very small. Each præmaxilla contained five teeth; these are followed by an interspace corresponding to the notch-like contraction of the snout where the præmaxillæ join the maxillæ. The maxillary series is unfortunately incomplete, owing to gaps in the hinder part of the maxillæ; but there were probably 18 teeth on each side. All which had come into use have been broken off at the level of the alveolar border or have fallen out: but the unworn crowns of three germs project slightly; they are bluntly pointed, stout, subcylindric, two-ridged, and striated. The ridges in two of the germs occupy a position intermediate between an antero-posterior and a transverse direction. In a piece of rock accompanying the skull are three similar teeth; the crown of the longest of these has, near its junction with the root, a transverse diameter of 0·8 inch. A small, strongly keeled, deeply pitted, unsymmetrical, pentagonal scute, two sides of which are mutilated, accompanied the skull.

II. *Crocodilian Skull in the British Museum* (No. 41,098). (Pl. XV. figs. 3 & 4.)

This skull was first brought under my notice, nearly four years ago, by Mr. Davies, the most obliging and able Assistant, who mentioned to me that it had a short time previously been acquired from a dealer, who had obtained it at Swanage. This statement of its locality was borne out by the rock in which it was imbedded, which had every mark of Purbeck rocks occurring near that town. Last June, whilst studying Mr. Willett's skull, I was struck with the general likeness of its upper surface to that of this Swanage skull; and, suspecting that the resemblance might also hold good with respect to the palato-nares, I expressed a wish that the stone might be removed from their situation. This was most obligingly done, and in their form, position, and construction the palato-nares were found to closely repeat those in Mr. Willett's and in the Brook skull, the most obvious difference being that the palate-bones seemed to bound rather more of the front half of the narial opening than in either of these. Less distorted by pressure, the shape of these openings is better seen in this Swanage skull (fig. 4). The posterior portion of the pterygoid bones (*pt*), nearly entire, are seen to unite mesially behind the nares between these openings and the middle Eustachian orifice (*Eu*), which latter they slightly conceal. This was apparent in the Brook skull, but, owing to mutilation, was not demonstrable in Mr. Willett's. In the Swanage skull the palate-bones (*pl*) widen out in front more rapidly than in the two other skulls, so that the pterygo-maxillary vacuities have a somewhat different figure, and they are also presumably smaller than in these skulls.

The upper surface of the skull, in its pitted ornamentation, resembles Mr. Willett's and the Brook skull; but the form of this part is less oblong, the transverse measurement just behind the orbits being shorter relatively to the occipital crest than in these. The orbits are much crushed, and the snout is also much flattened by pressure. It is broader, relatively to the length of the snout, than in either of the skulls to which reference has been frequently made, and the swelling at the longer teeth is greater, and it is also nearer the front of the snout.

The proportions of the length of the base and of the sides of the triangle which represent the occipital border and the sides of the skull and snout are not very different from those in Mr. Willett's skull, but the greater breadth of the snout (after allowance has been made for the flattening) gives the impression of a blunter form of head. I should also add that the upper surface is less strongly sculptured, being, in fact, nearly smooth. The nasal bones reach to about 1·2 inch from the anterior nares, and they end here less taperingly. The præmaxillæ and anterior nares resemble those of Mr. Willett's skull.

In the same slab with the skull were imbedded three scutes, one of a narrow oblong form, the smooth under surface of which is visible, and another having a strongly pitted trihedral centre surrounded by a smooth polyhedral border.

Since the discovery, in 1855, at Swanage, in the Purbeck beds, of the associated remains on which Prof. Owen founded the genus *Goniopholis* (*G. crassidens*, O.), no important addition has been made to our knowledge of this reptile; and the head had remained wholly unknown until Mr. Willett's fortunate acquisition (should this, as I have little doubt, prove to have been correctly referred by Mr. Willett to *Goniopholis*): some reservation with respect to its identification is, however, proper, because the characteristic marks of *Goniopholis* are its peculiar angulated pegged scutes, together with its stout, striated, slightly curved, two-ridged teeth. With Mr. Willett's skull are teeth closely agreeing in every essential point with those ascribed by Owen to *Goniopholis*; but the peculiar scutes are wanting to complete the identification. If this should be hereafter established, it will place *Goniopholis*, together with the Purbeck British-Museum skull (No. 41,098) and that from Brook in a group intermediate, as Prof. Huxley has shown with respect to the latter, between the Mesosuchia and Eusuchia.

As regards the construction and position of their palatal nares, these three crocodilian skulls resemble that of *Metriorhynchus Blainvillii* (Eudes Deslongchamps, 'Notes Paléont.' 1863–1869, pl. xx. fig. 1 *b*, reproduced by Prof. Huxley, Quart. Journ. Geol. Soc. vol. xxxi. pl. xix. fig. 3) more closely than any other Mesosuchian with which I am acquainted.

Upon a comparison of these skulls (Mr. Willett's and that from the isle of Purbeck) with those of extant Crocodilia, the general contour of the former (No. 41,098), viewed from above, is less elongated than in *Gavialis*, longer than in Alligatoridæ, and not very unlike that of a typical crocodile, as the *C. rhombifer* figured by Cuvier.

In the arrest of the nasal bones short of the anterior nares, the skulls of this group differ from those of alligators and of many crocodiles proper, and they resemble *Gavialis*, differing, however, from this in the further forward extension of the nasals. In this respect they more resemble the Bornean *Rhynchosuchus Schlegelii* and *Crocodilus cataphractus*; and to these they present another resemblance in the form of the palato-nares, which in *Rhynchosuchus* are more axially lengthened and less concealed by the centrally-joined plates of the pterygoid bones than in all other extant crocodiles.

I am inclined to look on Mr. Willett's and the Brook skull as belonging to one species, any differences being dependent on their widely different ages; and in order to avoid the multiplication of genera, I would provisionally place them both in *Goniopholis*, believing they will rest there. The Swanage skull (No. 41,098) should also find its place with them; but I suspect it will prove to be specifically distinct.

Holding, as they all three do, an intermediate position as to their palatal nares and other anatomical features, and occurring in time intermediately between the Mesosuchia of the Lias and Oolite and the Eusuchia (as has been shown by Prof. Huxley for the Brook skull), I would suggest that they may be properly placed in an intermediate subgroup of the Crocodilia, which, following Prof. Huxley's classification, might be designated *Metamesosuchia*.

Thus intercalated between the Liassic and Oolitic crocodilians represented by *Pelagosaurus typus*, *Metriorhynchus Blainvillii*, *Steneosaurus Larteti* on the one side, and the Eusuchia on the other, the palato-nares are seen to move backwards from the advanced position they occupy in *Pelagosaurus* (in which they are mainly placed between the divergent inner borders of the palatine bones), through this group (in which they are formed jointly by the palatines and pterygoids, the latter becoming connate between them and the median Eustachian opening), to the very posterior position they occupy in the Crocodilians of our own times.

The crushed condition of the Purbeck and Brook skulls makes it impossible to learn whether a distinct supraorbital bone is present in them, as it is in Mr. Willett's *Goniopholis*. From a comparison of it with the palpebral ossifications in *Caiman palpebrosus*, I doubt its homology with these; but I speak with reservation, as only young individuals of this *Caiman* have been at my disposal.

EXPLANATION OF PLATE XV.

Fig. 1. *Goniopholis crassidens?* (in Mr. Willett's collection), upper surface, one fourth natural size.

Fig. 2. Under surface of same.

Fig. 2 *a*. Tooth of *Goniopholis crassidens*, natural size.

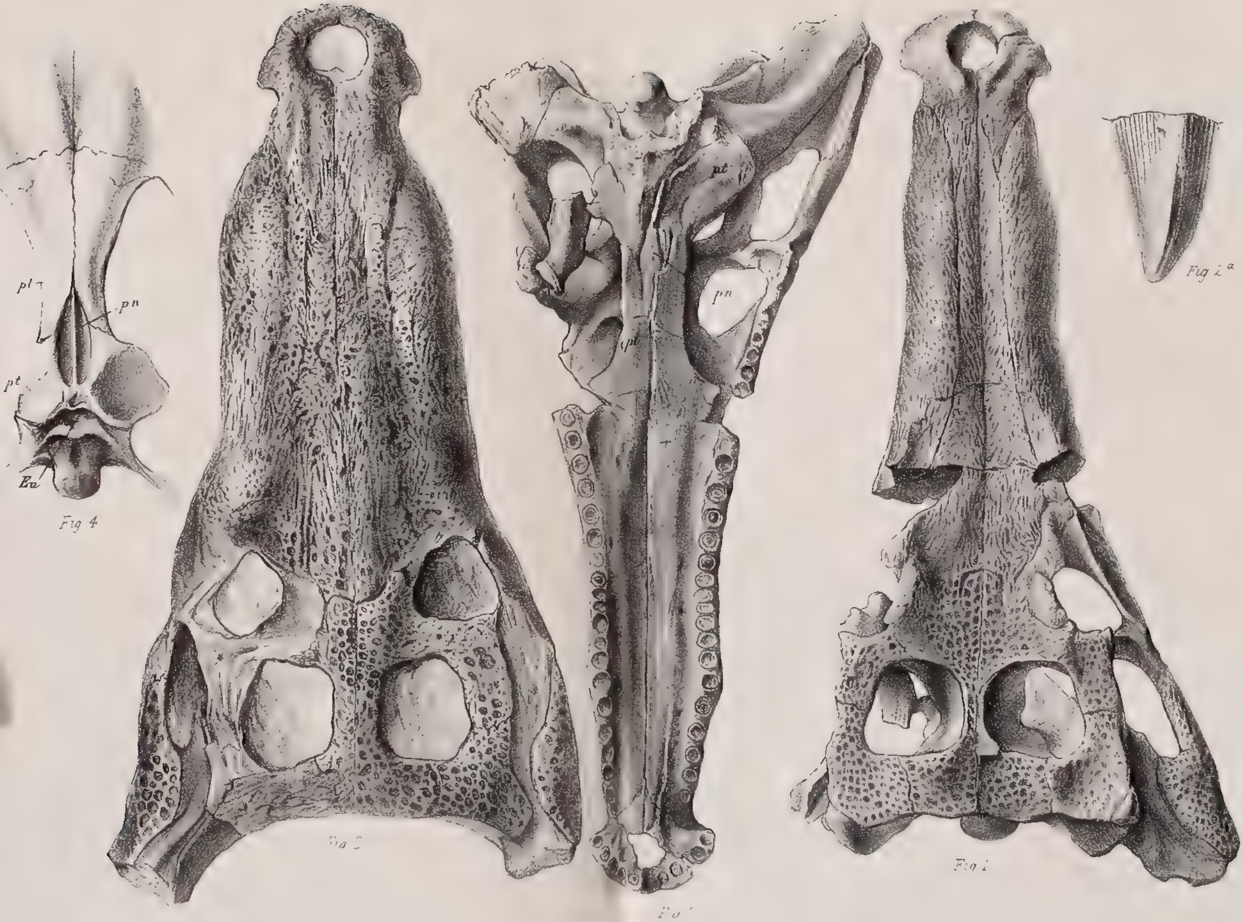
Fig. 3. Upper surface of skull No. 41,098 Brit. Mus., one fourth natural size.

Fig. 4. Under surface of same, showing the palato-nares.

In figs. 2 and 4: *pl*, palate-bone; *pt*, pterygoid bone; *pn*, palato-nares; *Eu*, median Eustachian orifice.

Discussion.

Prof. Owen said that 40 years ago he had entered on the study of the Wealden and Purbeck Crocodiles, the results of which appeared in the second part of his "Report on British Fossil Reptiles," in the volume of the British Association 'Reports' for 1841. He had then recognized two new genera, *Goniopholis* and *Suchosaurus*, besides Deslongchamps's *Poikilopleuron*, as British. In the expanded and illustrated form in which the subjects of the 'Report' have successively appeared as 'Monographs,' the Upper Mesozoic Crocodilia had waited to a late period. The new genus *Hylæochampsa* was issued in the Palæontographical volume for 1875; the new species of *Poikilopleuron* in that for 1876; the Purbeck Crocodiles in that for 1877. What he had to say on that subject had gone to press in that year. It was but yesterday that he had learned that Mr. Hulke had also been at work on that subject, and had suggested a part of the operations of clearing off matrix from specimens which were constantly and systematically subjected to such work on being received into the British Museum. In the volumes which Prof. Owen hopes shortly to issue on British Fossil Reptiles in general, Mr. Hulke's aid will be gratefully acknowledged.



J.L. Griesbach lith

Hanhart imp

GONIOPHOLIS

22. *On the* Glacial Deposits *of* West Cheshire, *together with* Lists *of the* Fauna *found in the* Drift *of* Cheshire *and* Adjoining Counties. By W. Shone, Esq., F.G.S. (Read November 21, 1877.)

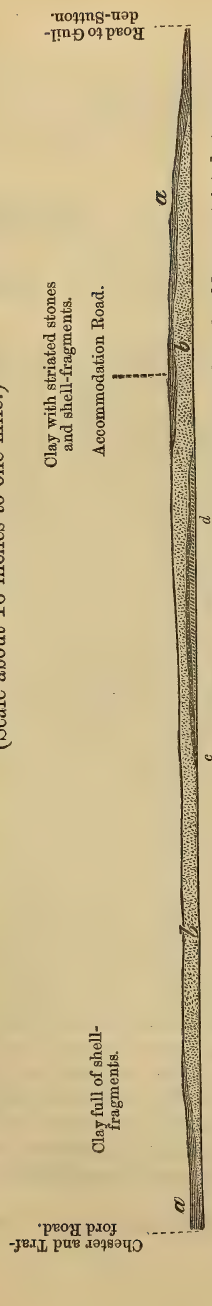
In March 1874, I communicated through Mr. D. Mackintosh, F.G.S., a paper on the "Discovery of Foraminifera, &c., in the Boulder-clays of Cheshire" (Quart. Journ. Geol. Soc. vol. xxx. p. 181). Since that time I have continued my observations, which I now place before the Society.

The extension recently of the Midland Company's line from Mouldsworth to Chester has caused interesting sections of the Drift to be exposed. The accompanying section to this paper exhibits that portion of the line which commences where the road from Hoole to Trafford crosses it, and is continued from that point for two miles and a quarter to a point a little beyond where the road from Trafford to Guilden-Sutton passes under the railway. From the commencement of the cutting at the Newton-road bridge to a spot near the top of Newton Hollows, a distance of half a mile, the Upper Boulder-clay through which it passes contains very few (if any) striated stones, and no shell-fragments, though small rounded gravel is present throughout it.

The cutting varies from 5 to 10 feet in depth up this point, consequently only the upper part of the clay is exposed; its entire thickness at the commencement of the section I estimate at 30 feet. The sand may at intervals be observed to crop out from beneath the clay in a dell which runs parallel to the railway-cutting, called Newton Hollows, proving its (the sand's) continuance beneath the clay throughout this part of the section. I am indebted to Mr. A. Strahan, B.A., F.G.S., for pointing out to me the outcrop of the sand in Newton Hollows. From near the top of Newton Hollows shell-fragments and striated erratics begin to be present, and continue to increase in number and size to where the basement of the Upper Clay resting upon the eroded surface of the Middle Sands is exposed near the bridge where the road from Chester to Trafford crosses over the railway. The characteristics of the Upper Boulder-clay are of the same persistence here as elsewhere over the plains of Lancashire and Cheshire; it is of a reddish-brown colour, broken into rude columnar structure by the cracking of the ground during seasons of drought. The faces of these rude columns are of a bluish-white colour, which is caused by the rain percolating from the surface down these cracks, and washing away, by reason of its slightly acidulated properties, the oxide of iron that colours the particles of the clay. These blue partings are very characteristic of the Upper Boulder-clay.

From the Newton section of the Upper Boulder-clay I have

Section in the Newton cutting of the Chester and West Cheshire Junction Railway.
(Scale about 16 inches to one mile.)



a. Upper Boulder-clay. *b.* Middle sand; fine sand with no boulders or striated stones.
c. Lower Boulder-clay full of striated boulders. *d.* Bunter Sandstone.

obtained 57 species and varieties of Mollusca, 2 Polyzoa, 26 Ostracoda, 2 Cirripedia, 2 Annelides, 3 Echini, 2 Sponges, and 55 Foraminifera.

The Microzoa were obtained from the sand within the Gastropoda found in the Clay, principally *Turritellæ*, upwards of 1500 of which shells I washed the sand out of, and examined for this purpose.

The Middle Sands were well exposed in that part of the section commencing from the Trafford-road bridge before mentioned, and continued on the north side of the cutting for the third of a mile, and gradually disappearing beneath the Upper Boulder-clay; the junction between the Clay and the Sand was sharp and eroded. The sand was very fine throughout, and contained no shell-fragments, except such as were of the size and roundness of the grains of sand. I examined it repeatedly for microscopic shells, but it yielded none. The shells in the Middle Sands are usually found in the seams of fine shingle which are generally present; in this case, however, though the exposure of the sand was a third of a mile in length, and of an average depth of 25 feet, the sand was uniformly fine throughout. It is again exposed, however, in a sand-pit at Upton, belonging to Sir Philip Grey-Egerton, Bart., F.R.S., a village about a mile and a half north-west of the section. From the Upton sand-pit, Mr. George W. Shrubsole, F.G.S., and myself have, after several years' diligent search, made a small collection of shells, the abundant forms being *Cardium edule*, *C. echinatum*, *Tellina balthica*, and *Turritella terebra*. The shells at the Upton pit only occurred in one seam of small shingle a few yards long and about 18 inches deep. The late Miss Eliza Potts, of Chester, first observed this fossiliferous seam many years ago; it was, however, forgotten, and rediscovered by Mr. Shrubsole. It is worthy of note that the *Turritellæ* and the other Gastropoda of the Middle Sands do not yield any Microzoa; the sand within them is azoic. Mr. De Rance, F.G.S., informs me that he has examined the sand from within the Gastropoda occurring in the Middle Sands of Blackpool with like results. This fact indicates that the conditions which obtained during the deposition of the Middle Sands were different from those under which the Upper and Lower Boulder-clays were formed; for in these for the most part the Gastropoda are filled with a fine greyish-white sand abounding with Microzoa, though the shells lie imbedded in a matrix of red clay. I shall attempt to give the explanation of this further on.

The shells from the Middle Sands and Gravels are, as a rule, more friable and much more *rolled* than those from the Boulder-clays.

In the section the sand was proved to a depth of 35 feet. There was not even a pebble, much less a boulder, found in it. The conspicuous absence of polished and striated erratics in the Middle Sands and Gravels is a marked feature. This sand is of the same horizon as that which covers the flanks of the Cheshire hills in the neighbourhood of Delamere, in which Sir Philip Grey-Egerton in 1835 and 1836 found marine shells, viz. *Cardium edule, Murex erinaceus*, and *Turritella terebra*. Sir Philip Grey-Egerton recently informed me that the pits at Wellington and Norley Bank, from which he obtained these shells (Proc. Geol. Soc. vol. ii. pp. 189, 415), have been long since closed.

The most interesting part of the section was that exposed near the accommodation-road bridge leading to a farm (see figure, p. 384. It is the next after the Trafford-road bridge to cross the line. Here the Lower Boulder-clay was exposed for a distance of 150 yards, and varying from 2 to 5 feet in thickness. It was evident, from the eroded surface of the Lower Boulder-clay at its junction with the Middle Sands above, that it was but a relic of the base of it which was here preserved, for the Lower Clay graduated into the coarse red sand of the disintegrated Bunter Sandstone immediately beneath. I have used the term Lower Boulder-clay; but the word "clay" must not be understood literally, as the stratum, though of the horizon of the Lower Boulder-clay, was composed half of dark red clay and half of coarse red sand from the rock beneath, mingled (but not mixed) confusedly together, especially at the base. No shell-fragments were observed. The erratics, however, abounded, being very much more numerous and very much larger than those in the Upper Boulder-clay before described, although of the same kind of rocks in both. The boulders in the Lower Clay consisted principally of Eskdale granite and Ennerdale syenite (identified by Mr. Mackintosh), decomposed greenstone, porphyry, Silurian grit, and (more rarely) Carboniferous Limestone, Millstone Grit, Keuper sandstone, gypsum, &c. Nine tenths of the erratics were polished and striated, the majority on two or more sides, a few only on one side, and striated along the longer axis.

The Lower Boulder-clay of Dawpool, Cheshire, described by Mr.

Mackintosh (Quart. Journ. Geol. Soc. vol. xxviii. p. 388), is not exposed at the base, and therefore cannot be compared with this section; but Mr. T. Mellard Reade, F.G.S., in his excellent paper on the "Drift-beds of the North-west of England" (Quart. Journ. Geol. Soc. vol. xxx. p. 27), describes the Lower Boulder-clay of Liverpool as possessing very similar characteristics.

The Fauna of the Drifts.

Having briefly noted the physical characteristics of these drift-deposits, the still more interesting subject, the fauna, remains to be discussed. The Upper Boulder-clay of the Newton section has yielded a great number of species, not, however, because the shells are more abundant than usual, but in consequence of the extent and duration of the exposure. The period of collection extended over about five years, and all the specimens have been picked from the clay by myself, with the exception of one *Natica sordida*, found in my presence by J. B. Manning, Esq., Constable of Chester Castle. Some thousands of fragments were thus obtained, which have been submitted from time to time to J. Gwyn Jeffreys, Esq., LL.D., F.R.S., F.G.S., who has examined and named them. I cannot sufficiently express my thanks to that gentleman for his uniform courtesy and kindness in having undertaken so much difficult and tedious labour.

Of the fifty-six species and varieties which occur in the Upper Boulder-clay of Newton, the following are known to be living in Arctic and Scandinavian seas, but are not as yet admitted to be living on the British shores:—

Leda pernula.	Natica affinis.
Astarte borealis.	Admete viridula.
Tellina calcarea.	Pleurotoma pyramidalis.
Dentalium striolatum.	

The following Mollusca found at Newton are living in British seas, but belong to the northern type of our fauna, as they inhabit Arctic and Scandinavian seas in common with our own:—

Mytilus modiolus.	Buccinum undatum.
Cyprina islandica.	Trophon clathratus, var. truncata.
Astarte compressa, var. striata.	Pleurotoma rufa.
Lacuna divaricata.	—— turricula.

The following Mollusca found at Newton are living in British seas, and belong to the southern type of our fauna:—

Arca lactea.	Natica sordida.
Venus chione.	

The remaining thirty-eight species found at Newton are not pronounced either northern or southern forms, and do not therefore indicate any particular climatic conditions.

In the Middle Sands at Upton, out of twenty-three species found jointly by Mr. Shrubsole and myself, two are Scandinavian, *Astarte borealis*, *Dentalium striolatum*, and four British, but of northern type, viz. *Mytilus modiolus*, *Cyprina islandica*, *Buccinum undatum*, and *Trophon clathratus*, var. *truncata*. The remaining seventeen species are of no special interest.

From the Lower Boulder-clay of Dawpool, Cheshire, out of thirty-five species, the following are Arctic and Scandinavian forms:—

Leda pernula.	Natica affinis.
Astarte borealis.	Fusus despectus.

The following are British shells of northern type:—

Mytilus modiolus.	Trophon clathratus, var. truncata.
Cyprina islandica.	Pleurotoma rufa.
Lacuna divaricata.	—— Trevelyana.
Buccinum undatum.	

The remaining twenty-four species are of no special interest.

Dr. Gwyn Jeffreys, in the notes attached to the lists of the foregoing Mollusca from the Upper Boulder-clay of Newton, Middle Sands of Upton, and the Lower Boulder-clay of Dawpool, Cheshire, says, "The fauna is Scandinavian, with the exception of *Arca lactea*, *Venus chione*, and *Natica sordida*," the southern species which occur in the Upper Boulder-clay of Newton.

The Ostracoda in the sand within the shells of the Gastropoda from the Boulder-clays of Dawpool, Newton, and Liverpool were named by the Rev. H. W. Crosskey, F.G.S., and he states that "the group could not as a whole be called a decidedly Arctic one; but it has a generally northern character, and quite agrees with your description of the fauna," viz. boreal.

The Foraminifera do not indicate any special climatic conditions. They are all British species, the whole of which have been found by Mr. J. D. Siddall, Chester, and my mother, Mrs. Shone, in the estuary of the Dee.

It is of importance to note that the whole of the fauna from the drifts of this district, whether of Mollusca, Ostracoda, or Foraminifera, belong to littoral or sublittoral species, the commonest shore-forms being the most abundant; so persistent is this littoral character of the fauna that the question naturally arises, Are the localities from which they are obtained the sites of ancient raised sea-beaches? This query opens out the whole subject of the mode of occurrence and condition of the shells. Mr. Reade, in the paper before referred to (Quart. Journ. Geol. Soc. vol. xxx. p. 31), suggests tidal currents as the principal means by which the shells were distributed. I am of the same opinion, that currents did distribute the shells in the *Middle Sands and Gravels*, because they occur in the *bands of fine shingle*, showing that they have been *sorted* according to *their weight*; also it is worthy of note that the Gastropoda are consequently not filled with *fine sand*, but with the *coarse* sand in which they lie *imbedded*, which on examination has *never* yet yielded Microzoa. Then current bedding is very frequent, especially where shingle bands occur in the Middle Sands; and the shells are more rolled than in the Boulder-clays. The fragmentary condition of the shells, and the fact that the wo valves of the bivalve Mollusca are never found united either in the clays or the sands, are so well known as hardly to require mention. The condition in which Mr. Reade has described the Mollusca as occurring in the Liverpool Boulder-clay is so exactly similar to that in which the shell-fragments occur in the Boulder-clays of Newton and Dawpool that I might copy his remarks word for word. I shall therefore simply refer to his paper (Quart. Journ. Geol. Soc. vol. xxx. p. 31).

With regard to the shells in the Boulder-clays, all observers are agreed that they are not *in situ*, and that they have been transported; but how?

I think that the Boulder-clays bear every evidence of deposition in still water, the particles which compose them being for the most part very fine. For instance, if a piece of Boulder-clay be dissolved in a test-tube filled with sea-water, and then shaken up, it is some time before the fine unctuous mud is redeposited. I think this is a very important fact, when we consider that the Upper Boulder-clay for the most part is spread out in one uniform sheet over the lowlands of Lancashire and Cheshire from the sea to a height of some 500 or 600 feet. I cannot imagine currents at once strong enough to sweep along the shells from the then existing beaches, and at the same time allowing the finest particles of the clay to be deposited. Again, the Gastropoda throughout this clay are usually filled with the very finest greyish-white sand full of Microzoa; would not these currents in rolling them along have swept out this fine greyish-white sand and replaced it with the red Boulder-clay in which they lie imbedded? as it is, however, those filled with Boulder-clay are the exception, instead of being the rule. This argument is also equally applicable to those who maintain that the Upper Boulder-clay is derived, together with its shells, stones, striated erratics, and Scandinavian fauna—in short, that it is not a glacial clay at all.

The mode of the transportation of the shells in face of all these difficulties has long been a puzzle. In the early part of 1875 there was a short, but for the time a very severe frost. At the mouth of the Dee there is an island called Hilbre, some five acres in extent; it is distant across the sands about a mile and a half from the Cheshire shore; this space is covered with water at half-tide. The dead shells of the Mollusca, Ostracoda, Foraminifera, &c. which live in the Laminarian zone are cast up and left by the receding tide between the ripple-marks on the sands. The dead shells of the Gastropoda, as they lie in these hollows, get more or less filled with the fine silt containing the Microzoa. The frost was severe enough to freeze the water left in these furrows by the receding tide; consequently the Gastropoda filled with this silt, the broken shells, &c. were enclosed in thin sheets of ice, which were broken up on the return of the tide, and such as were cast ashore on Hilbre Island were piled together and frozen into blocks. When the thaw commenced it set these blocks free. Charged with the Gastropoda and broken shells, these tiny ice-rafts floated short distances away, distributing as they melted their load of broken shells, and casting the silt-filled Gastropoda over the mud-flats of the delta of the Dee.

I do not think I can offer a better explanation than this of the manner in which the shells were distributed in the Boulder-clays, and how the Gastropoda filled with silt containing Microzoa are found in a matrix of red clay. That the Gastropoda so filled are spread over a wide area I am able to affirm, having obtained them from various localities in Boulder-clays in Lancashire, Cheshire, Flintshire, Denbighshire, Shropshire, Staffordshire, and the Isle of Man. With regard to height above the sea, the Gastropoda containing silt with Microzoa are as common to the Boulder-clay of Macclesfield, which overlies the Middle Sands and Gravels, and that at Arnfield, Cheshire, above 600 feet up on the flanks of the Pennine Chain, as they are at the sea-level in the Lower Boulder-clay of Dawpool*. Among the Foraminifera *Rotalia Beccarii* and *Bulimina pupoides* are the most persistent species, being found in the Gastropoda from the Boulder-clay of Macclesfield and Arnfield to that of all the counties above mentioned. They are two of the most common littoral species of our shores. The Scandinavian facies of the fauna from the Upper and Lower Boulder-clays establishes that the climate would be cold enough for the formation in winter of coast-ice on the then shores, while the employment of ground-ice for the distribution of the shells in the Boulder-clays does away with the difficulty of the deposition of the finer particles of the clay, as the water might be sufficiently still in the depths of the sea for its accumulation, while the ice-rafts from the coasts were floating upon the surface, discharging as they melted their freights of sand, broken shell, gravel, and striated erratics gathered from the more distant beaches. This would account for the fauna being littoral and sublittoral, and of species whose habitats are among seaweeds, rocks, and sands being mingled confusedly together in a common matrix of clay.

The mingling of northern and southern forms together in the drifts demands some explanation. From an analysis of the fauna of these deposits in Lancashire and Cheshire, it appears that northern shells are more common in the clays, and rarer in the Middle Sands and Gravels, while, on the other hand, southern shells are rare in the Clays and more common in the Middle Sands and Gravels. If we turn to the physical aspect of the drift, it will help us to clear up the difficulty. Thus, the Lower Boulder-clay at its junction with the Middle Sands and Gravels is most generally eroded, and bears the marks of having once been far more extensive than at present. The Lower Boulder-clay contains a Scandinavian fauna; is it not therefore more than probable that the Scandinavian shells of the Middle Sands and Gravels have been derived from the Lower Boulder-clay? and thus we have, as at Leylands, *Trophon Fabricii* with *Mactra glauca*, and again, at Macclesfield, *Astarte borealis* with *Arca lactea*. Again, if we examine the gravels, we find them largely composed of the granites, porphyries, limestones, and grits which

* Mr. R. D. Darbishire, B.A., F.G.S., gave me some silt &c. containing Foraminifera which he had gathered from the beach at Gorteen, Connemara, Ireland. My mother, Mrs. Shone, on examining this débris, observed that the fry of the Gastropoda, which abounded in it, were all filled with this Foraminiferal silt, and only awaited the formation of ground-ice on the shore to repeat the phenomenon of the Gastropoda of the Boulder-clays.

occur as striated erratics in the Lower Boulder-clay, the difference, in fact, being that in the Middle Gravels they are rounded and the striæ obliterated, while in the Lower Boulder-clay they are angular, subangular, polished, and scratched. If it be reasonable to derive the gravels chiefly from this source, it is equally reasonable to derive the Scandinavian shells found in the Middle Sands from the same source.

Also if we examine the junction between the Upper Boulder-clay and the Middle Sands and Gravels, the latter are very much eroded, so much so that they form dome-like masses with the clay filling up the hollows. The Middle Sands and Gravels contain southern shells; what, therefore, more likely than that the southern forms, which are very rare in the Upper Boulder-clay, should have been derived from the Middle Sands, and so explain away the apparent inconsistency of such shells as *Admete viridula*, *Natica affinis*, and *Pleurotoma pyramidalis* occurring in the Upper Boulder-clay of Newton side by side with *Arca lactea*, *Venus chione*, and *Natica sordida*?

At the Dawpool Cliffs the River Dee is carrying away the Lower Boulder-clay, and its Scandinavian fauna is being mingled and redeposited in the delta with the shells of recent species inhabiting the estuary.

We appear, therefore, to have, as suggested by Prof. Hull, F.R.S., a threefold division of the Glacial drift, although I think it is to be regretted that the terms Lower Boulder-clay, Middle Sands and Gravels, and Upper Boulder-clay should have been chosen to express the phenomena of any particular periods, as we cannot but imagine that clays, sands, and gravels were in course of deposition during all these periods, though of course one or other may have locally predominated at specified intervals. I think that Lower Glacial Drift for Lower Boulder-clay, Interglacial Drift for Middle Sands and Gravels, and Upper Glacial Drift for Upper Boulder-clay would be more comprehensive.

In conclusion, I believe we have here evidence of a Glacial age, marked in the lowlands of the west coast of England by the marine Lower Boulder-clay; that it was succeeded by a temperate age, represented by the Interglacial Middle Sands and Gravels*, with their southern Mollusca, as *Arca lactea*, *Venus chione*, &c., the boreal forms having been *derived* from the denudation of the Lower Boulder-clay; and, lastly, that in the Upper Boulder-clay we have evidence of a partial return to Glacial conditions like those of the Lower Boulder-clay era, though not so severe, the climate being Scandinavian.

In the following Tables of Foraminifera and Ostracoda, the species marked 1 in the Liverpool column were found by Mr. T. Mellard Reade, F.G.S., and Mr. David Robertson, F.G.S., not in *Turritellæ*, however, but free in the Boulder-clay; those marked * in this column were found by me in the sand from within *Turritellæ* which were sent to me by Mr. Reade (see Quart. Journ. Geol. Soc. vol. xxx. p. 29).

* Mr. D. Mackintosh, F.G.S., has recently, on physical grounds, suggested the Interglacial character of the Middle Sands and Gravels. I rest my opinion, however, more upon the southern fauna.

FORAMINIFERA.

	U. B. Clay, Newton. W. Shone.	U. B. Clay, Liverpool. W. Shone and T.M.Reade.	L. B. Clay, Dawpool. W. Shone.
Cornuspira involvens, *Philippi*	*	*	
Biloculina ringens, *Lamk.*	*	1	*
—— elongata, *D'Orb.*	*		
Triloculina trigonula, *Lamk.*	*	...	*
—— oblonga, *Montagu*	*	...	*
Quinqueloculina seminulum, *Linn.*	*	*1	*
—— bicornis, *W. & J.*	*	*	
—— secans, *D'Orb.*	*	*	
—— subrotunda, *Montagu*	*	*	*
—— agglutinans, *D'Orb.*	*	...	*
—— Ferussacii, *D'Orb.*	*	1	
Lituola scorpiurus, *Mont.*	*		
—— canariensis, *D'Orb.*	*		
Lagena sulcata, *W. & J.*	*	1	*
—— lævis, *Montagu*	*	*	*
—— striata, *D'Orb.*	*	*	
—— semistriata, *Will.*	*		
—— globosa, *Montagu*	*	*1	
—— marginata, *W. & J.*	*	1	
—— lucida, *Will.*	*	*	*
—— squamosa, *Montagu*	*	1	*
Nodosaria scalaris, *Batsch.*	*		
—— radicula, *Linn.*	*	...	*
—— pyrula ?, *D'Orb.*	*		
Dentalina communis, *D'Orb.*	*	...	*
Cristellaria rotulata, *Lamk.*	*	*	*
—— crepidula, *F. & M.*	*	...	*
Polymorphina communis, *D'Orb.*	*	*	
—— lactea, *W. & J.*	*	*	
—— compressa, *D'Orb.*	*	1	
—— myristiformis, *Will.*	...	...	*
Uvigerina angulosa, *Will.*	*	*	
Orbulina universa, *D'Orb.*	*		
Globigerina bulloides, *D'Orb.*	*	*	*
Textularia variabilis, *Will.*	*	*	*
—— globulosa, *Ehrenb.*	*		
—— pygmæa, *D'Orb.*	*	*	*
—— difformis, *Will.*	*	*	*
Bulimina pupoides, *D'Orb.*	*	*1	*
—— marginata, *D'Orb.*	*	...	*
—— aculeata, *D'Orb.*	*	*	
—— ovata, *D'Orb.*	*	*	*
—— elegantissima, *D'Orb.*	*	*	*
—— spinulosa ?, *Will.*	*		
Virgulina Schreibersii, *Czjzek*	...	*	
—— spinulosa, *Reuss*	*		
Bolivina plicata, *D'Orb.*	*	*	*
Cassidulina lævigata, *D'Orb.*	*		
—— crassa, *D'Orb.*	*	...	*
Discorbina rosacea, *D'Orb.*	*	*1	
—— globularis, *D'Orb.*	*	*	
Planorbulina mediterranensis, *D'Orb.*	*		

Foraminifera (*continued*).

	U. B. Clay, Newton. W. Shone.	U. B. Clay, Liverpool. W. Shone. and T.M.Reade.	L. B. Clay, Dawpool. W. Shone.
Truncatulina lobatula, *Walker*	*	*1	*
—— refulgens, *Mont.*	*		
Pulvinulina repanda, *F. & M.*	*	*	
Rotalia Beccarii, *Linn.*	*	*1	*
—— nitida, *Will.*	*	*	*
Patellina corrugata, *Will.*	*		
Polystomella crispa, *Linn.*	*	1	
—— striato-punctata, *F. & M.*	*	*1	*
Nonionina umbilicatula, *Montagu*.........	*	...	*
—— depressula, *W. & J.*	*	*1	*
—— asterizans, *F. & M.*......................	*	*1	*

Ostracoda.

The following Ostracoda have been submitted for identification of the species to the Rev. H. W. Crosskey, F.G.S., and G. S. Brady, Esq., F.L.S., F.G.S., to whom my best thanks are due.

	U. B. Clay, Newton. W. Shone.	U. B. Clay, Liverpool. W. Shone.	L. B. Clay, Dawpool. W. Shone.
Cythere pellucida, *Baird*	*		
—— tenera, *Brady*	*	...	*
—— cribrosa, *B., C., & R.*	...	...	*
—— finmarchica, *G. O. Sars*...............	*		
—— villosa, *G. O. Sars*......................	*		
—— concinna, *Jones*	*	*	*
—— tuberculata, *G. O. Sars*	*	*	*
—— dunelmensis, *Norman*	*		
—— Whiteii, *Baird*	*		
—— antiquata, *Baird*.........................	*		
—— Jonesii, *Baird*.............................	*	*	
Cytheridea papillosa, *Bosquet*	*	1†	*
—— punctillata, *Brady*.......................	*	...	*
—— Sorbyana, *Jones*	*		
Eucythere argus, *G. O. Sars*	*		
Krithe bartonensis, *Jones*	...	...	*
Loxoconcha impressa, *Baird*	*		
—— guttata, *Norman*..........................	*	...	*
—— tamarindus, *Jones*	*	*	*
Cytherura striata, *G. O. Sars*	*	*	*
—— angulata, *Brady*..........................	*		
—— producta, *Brady*	*		
Cytheropteron latissimum, *Norman*	*		
—— nodosum, *Brady*	*		
—— montrosiense, *B., C., & R.*	...	*	*
Sclerochilus contortus, *Norman*............	*		
Paradoxostoma ensiforme, *Brady*	*	...	*
—— flexuosum, *Brady*	*	...	*
—— arcuatum, *Brady*	*	*	

† Mr. T. M. Reade, F.G.S.

Analysis of the principal Collections of Shells from the Drift of Lancashire and Cheshire, also Moel Tryfaen.

	Moel Tryfaen.	Lower Boulder-clay, Dawpool, Cheshire.	Middle Sands and Gravels.				Upper Boulder-clay.	
			Macclesfield, Cheshire.	Leylands, Lancashire.	Blackpool, Lancashire.	Upton, Cheshire.	Newton, Cheshire.	Liverpool, Lancashire.
Arctic and Scandinavian species not as yet admitted to be inhabitants of British Seas (authority J. Gwyn Jeffreys's 'British Conchology'):—								
Leda pernula	r	r	...	...	...	...	v r	v r
Astarte depressa (crebricostata)	v r							
—— borealis	c	c	c	f	c	r	a	c
Tellina calcarea	r	...	...	...	...	...	f	
Dentalium striolatum	v r	...	v r	...	...	v r	f	
Natica affinis	r	r	...	...	...	...	v r	
Admete viridula	...	...	...	...	...	...	v r	
Fusus despectus	...	v r						
Trophon clathratus, var. scalariformis	f							
—— ——, var. Gunneri	f							
—— Fabricii	?	...	...	v r				
Pleurostoma pyramidalis	v r	...	...	...	...	...	f	
	9	4	2	2	1	2	7	2
Northern type of British species which inhabit Arctic and Scandinavian Seas in common with our own:—								
Mytilus modiolus	r	v r	r	f	...	r	f	f
Cyprina islandica	c	f	c	f	f	f	a	c
Astarte compressa	c	...	...	...	...	...	...	r
—— compressa, var. striata	...	...	...	...	...	...	v r	
Saxicava norvegica	...	...	...	v r	...	...	...	v r
Lacuna divaricata	v r	f	...	...	...	...	r	
Natica grœnlandica	...	...	...	...	...	...	...	v r
Trichotropis borealis	v r							
Buccinum undatum	f	f	r	f	f	f	f	f
Trophon barvicensis	v r							
—— clathratus, var. truncata	f	f	f	f	r	r	c	f
Fusus islandicus	...	...	...	...	...	...	...	r
—— gracilis	v r	...	v r	v r				
—— propinquus	...	...	...	v r				
Pleurotoma rufa	v r	...	v r	...	...	...	v r	v r
—— turricula	f	r	f	...	...	...	f	r
—— Trevelyana	...	r						
	11	7	7	7	3	4	8	10
Southern type of British species which inhabit more southern seas in common with our own:—								
Arca lactea	...	...	v r	...	...	...	v r	
Venus chione	...	...	f	r	r	...	v r	r
Natica sordida	...	...	...	...	...	...	v r	
			2	1	1		3	1

In the Tables of Mollusca v r means that 1 to 3 specimens have occurred; r, 3 to 10; f, frequent; c, common; a, abundant; v, very.

I consider Moel Tryfaen to be the oldest of all these deposits, because there are no southern shells mixed with its Scandinavian fauna.

	Arctic and Scandinavian Mollusca.	British Mollusca of northern type.	British Mollusca of southern type.	Number of remaining species found, but of no climatic value.	Total number of species found.
Newton. Boulder-clay	7	8	3	38	56
Liverpool. ,, ,,	2	10	1	31	44
Dawpool. ,, ,,	4	7	...	24	35
	13	25	4	93	135
Upton. Middle Sands and Gravels	2	4	...	17	23
Macclesfield. ,, ,, ,,	2	7	2	37	48
Leylands. ,, ,, ,,	2	7	1	34	44
Blackpool. ,, ,, ,,	...	3	1	18	22
	6	21	4	106	137

From this Table it will be seen that Arctic and Scandinavian Mollusca are more common in the Boulder-clays than they are in the Middle Sands and Gravels. Figures, however, do not give so clear a notion of the importance of the relative absence of many of the Scandinavian species from the Middle Sands and Gravels as may be obtained from a study of the more detailed analysis, where each species may be followed, and its frequency or infrequency throughout the drift deposits observed.

In the accompanying lists of the Mollusca, the Lancashire localities I have taken from the Memoir of the Geological Survey "On the Superficial Geology of the Country adjoining the Coasts of Southwest Lancashire," by C. E. De Rance, Esq., F.G.S. I have compared, however, the Blackpool, Leylands, and Liverpool lists of shells with the published lists of R. D. Darbishire, Esq., B.A., F.G.S. (Geol. Mag. vol. ii. p. 298; Quart. Journ. Geol. Soc. vol. xxx. p. 38), and T. Mellard Reade, Esq., F.G.S. (Quart. Journ. Geol. Soc. vol. xxx. p. 27), and I have corrected the errors which occur in the lists of the Survey publication.

I have to thank Mr. Darbishire for correcting his Macclesfield and Moel-Tryfaen lists, published Geol. Mag. vol. ii. p. 298.

The Mollusca from Newton were found by myself.

The Mollusca from Upton were found by G. W. Shrubsole, Esq., F.G.S., and myself.

[To face p. 394.

LIST OF MOLLUSCA &c. FROM THE DRIFTS OF LANCASHIRE, CHESHIRE, &c.

	LANCASHIRE								CHESHIRE							
Mactra solida, *L.*	......	U L 2	3	2	2	......	r	r	r	r	r	*	*	......	*	*
— gracilis, *Du C.*	......	....	....	......	2	......	v r	......	...	v r						
— propinquus, *Ald.*	......	....	....	......	2											
— despectus, *L.*			....		...		...	v r								

List of Mollusca &c. from the Drifts of Lancashire, Cheshire, &c.

	Lancashire. Lower Boulder-clay. 1. Preston, C. E. De Rance. 2. Blackpool, " 3. Scarisbrick, "	Lancashire. Lower Boulder-clay. Liverpool District, Linacre, &c. 1. G. Morton. 2. T. M. Reade. 3. I. Roberts.	Lancashire. Middle Sands and Gravels. Blackpool. 1. Rev. Mr. Thornber. 2. E. W. Binney. 3. R. D. Darbishire. 4. C. E. De Rance.	Lancashire. Middle Sands and Gravels. 1. Garstang, C. E. De Rance. 2. Preston, " 3. Ribble Valley, "	Lancashire. Middle Sands and Gravels. 1. Chorley, C. E. De Rance. 2. Leyland, Miss Ffarington.	Lancashire. Upper Boulder-clay. 1. Garstang, C. E. De Rance. 2. Blackpool, " 3. Preston, "	Moel Tryfaen, Caernarvonshire, R. D. Darbishire.	Lower Boulder-clay, Dawpool. D. Mackintosh. W. Shone.	Cheshire. Middle Sands and Gravels. Prestwich's Patch, Macclesfield.	Cheshire. Middle Sands and Gravels. Macclesfield, R. D. Darbishire.	Cheshire. Middle Sands and Gravels. Upton, G. W. Shrubsole, W. Shone.	Cheshire. Middle Sands and Gravels. Warrington, Mr. Paterson.	Cheshire. T. M. Reade. Boulder-clay, Birkenhead.	Cheshire. W. Shone. Upper Boulder-clay, Newton-by-Chester.	Gravel, Lilleshall, Salop, C. T. Woodward.	Middle Sands and Gravels, Stretball, Buildwas, Salop. Geo. Maw.
Anomia ephippium, *Linné*														v r		*
Ostrea edulis, *L.*	2	U 1 2 3	3	2 3	2	2 3	v r			v r	r			f		*
Pecten opercularis, *L.*		U 2 3		2 3	2	2	r	r		v r	r	*		f	*	*
Mytilus edulis, *L.*	1 2			2	1	3	f	v r	v r	f	r			f	*	*
—— modiolus, *L.*		U L 2			2		r	v r		r	r		*	f		*
Nucula nucleus, *L.*														v r		
Leda pernula, *Müller*		U 2					r	r						v r		
Pectunculus glycymeris, *L.*		U 2		2 3	2		v r			v r				f		
Arca lactea, *L.*										v r				v r		
Cardium aculeatum, *L.*										?						
—— echinatum, *L.*		U L 2 3	3		1 2	1 2 3	r	c	r	f	c		*	a	*	*
—— tuberculatum, *L.*		U 2		1 2 3	1 2	2 3		v r		r						
—— fasciatum, *Montagu*							f									
—— edule, *L.*	1 2 3	U L 1 2	3 4	1 2 3	1 2	1 2 3	c	a	f	c	a		*	a	*	*
—— norvegicum, *Spengler*					1 2		r	v r		v r						
Cyprina islandica, *L.*		U 1 2 3	3 4	1 2 3	1 2		c	f	c	c	f	*	*	a	*	*
Astarte sulcata, *Da Costa*		U 2	3 4		2			v r			r			r		
—— sulcata, var. elliptica		U 2		3	2		f	f		r		?		f		
—— compressa, *Montagu*		U L 2					c					?	*			
—— compressa, var. striata														v r		
—— depressa (A. crebricostata, *Forbes*)							v r									
—— borealis, *Chemnitz*		U L 2		1 2 3	1 2	1 3	c	c	v r	c	r	*	*	a	*	*
Venus exoleta, *Linné*		U 2		2			v r									*
—— lincta, *Pulteney*		U 2		2					r	r				v r		*
—— chione, *L.*		U L 2	4	2	2	2			r	f				r		
—— casina, *L.*					2		v r							v r		
—— verrucosa, *L.*																*
—— gallina, *L.*		U 2	3		2		v r			r				f		*
Tapes virgineus, *L.*		U 2		2			v r							v r		
—— pullastra, *Montagu*					2											
Tellina balthica, *L.* (T. solidula, *Pult.*)		U L 1 2 3	3 4	1 2 3	2	1 2 3	a	a	f	a	a	*	*	v a	*	*
—— calcarea (T. proxima, *Brown*)							r							f		*
Psammobia ferröensis, *Ch.*	2	U 2	4	2	2	2		f	v r	f	r	*	*	f	*	*
Donax vittatus, *Da C.*		U 2		2			v r			v r						
Mactra solida, *L.*		U L 2	3	2	2		r	r	r	r	r	*	*		*	*
—— solida, var. elliptica							v r							c		
—— subtruncata, *Da C.*			3					v r						v r		
—— glauca, *Born* (M. helvacea, *Ch.*)					2											
Lutraria elliptica, *Lamarck*		L U 2 3		2 3	2			v r		v r					*	
Scrobicularia alba, *Wood*								v r								
—— piperata, *Bellonius*		U 2														
Solen siliqua, *L.*					2											
Thracia pubescens, *Pult.*														v r		
Corbula gibba, *Olivi* (C. nucleus, *Lam.*)			3				v r			v r				v r		
Mya arenaria, *L.*										v r						
—— truncata, *L.*		U L 2	3 4		2		f	f		f	r	*	*	c		*
—— truncata, var. uddevallensis							v r									
Saxicava norvegica, *Sp.*		U 2			2											
—— rugosa, *L.*	1 2	U 2			2		r							r		
—— rugosa, var. arctica							v r							r		*
Pholas candida, *L.*								r		?						
—— crispata, *L.*	1 2	U 2			2	2				v r				v r	*	*
Teredo norvegica, *Sp.*																*
Dentalium entalis, *L.*	2	U 2		1 2 3	2	2	v r			r		*		f		*
—— tarentinum, *Lam.*		U 2														
—— striolatum, *Stimpson* (D. abyssorum, *Sars*)							v r			v r	v r			f	*	
Patella vulgata, *L.*			2 4							?						
Fissurella græca, *L.* (F. reticulata, *F. & H.*)							v r			v r						
Trochus magus, *L.*																*
—— cinerarius, *L.*			4							v r	r					
—— umbilicatus, *Mont.*																*
Lacuna divaricata, *Fabricius*							v r	f						r		
Littorina obtusata, *L.*			2 3 4		2					?				v r		
—— rudis, *Maton*			2 3 4			2	v r			v r				f		*
—— litorea, *L.*		U 1 2 3	4	1 2 3	2		f	f		v r		*		c		*
Homalogyra atomus, *Philippi*														v r		
Turritella terebra, *L.*	1 2 3	U L 1 2 3	4	1 2 3	2	2	a	a	f	a	a	*	*	v a	*	*
Scalaria communis, *Lam.*														v r	*	
Odostomia interstincta, *Mont.*														v r		
Natica grœnlandica, *Beck*		U L 2														
—— sordida, *Ph.*														v r		
—— catena, *Da C.*			3	1 3	2					v r	v r					
—— Alderi, *Forbes*										?				v r		
—— affinis, *Gmelin* (N. clausa, *Broderip & Ponsonby*)							r	r						v r	*	
Admete viridula, *Fabricius*														v r		
Trichotropis borealis, *Brod. & Sow.*							v r									
Aporrhais pes-pelecani, *L.*		U 2 3	2 3 4	3	1 2		v r	r		v r	r			v r	*	*
Purpura lapillus, *L.*		U 1 2 3	3 4	1 2 3	1 2	2	f	f		f	f	*		f	*	*
Buccinum undatum, *L.*	2	U L 1 2 3	2 3 4	2 3	1 2		f	f		r	f	*	*	f	*	*
Murex erinaceus, *L.*	2	U 1 2	2 3 4	3	2		r	f		f	f			f		*
Trophon barvicensis, *Johnston*							v r									
—— clathratus, *L.*, var. truncata		U 2 3	3		2		f	f		f	r	*		c	*	
—— ——, var. Gunneri							f									
—— —— (scalariformis, *Gould*)			4	2 3	1 2		f									
—— Fabricii, *Monro*, var. craticulatus, *Fabr.*					2		?									
Fusus antiquus, *L.*		U 2	3 4	1 2 3	1 2		c	r	v r	r		*		v r	*	*
—— antiquus, monstr. contrarium					2											
—— islandicus, *Ch.*		3		3												
—— gracilis, *Da C.*					2		v r			v r						
—— propinquus, *Ald.*					2											
—— despectus, *L.*								v r								
Nassa reticulata, *L.*	2	U L 1 2 3	2 3 4	1 2 3	1 2		r	r		v r	f	*		r	*	*
—— incrassata, *Strom*	2	U 1 2			2		v r	r		v r						
Pleurotoma nebula, *Mont.*							v r									
—— rufa, *Mont.*		U 2 3					v r			v r				v r		
—— turricula, *Mont.*		U 2			2		f	r		f		*		f		*
—— Trevelyana, *Turton*								r								
—— pyramidalis, *St.*							v r							f		
Cypræa europæa, *Mont.*			3							v r				v r		
Polyzoa.																
Salicornaria Cuvieri, *Lam.*		U 2						v r						r		
Lepralia Peachii, *Johnston*														v r		
For Ostracoda see separate list for those found at Liverpool, Newton, and Dawpool.																
Cirripedia.																
Balanus crenatus, *Brug.*			3				r	r						v r		
—— sulcatus, *Lam.*														v r	*	*
—— balanoides, *L.*																*
—— Hameri, *Ascanius*							v r									*
—— porcatus, *Da C.*					2											
Annelida.																
Serpula vermicularis, *Ellis*														v r		
Spirorbis nautiloides, *Lam.*								r						r		*
Pomatoceros triquetra *on* Ostrea edulis																
Echinoidea.																
Cidaridæ, spines of, from the sand within Gastropoda		*						f						f		
Spatangidæ, spines of, from the sand within Gastropoda		*						f						f		
Toxopneustes dröbachiensis, *Müll.*														v r		
Spongida.																
Cliona, sp., in shells			3 4		2		v r	r		r	r			r		*
Grantia, sp., spicula of, from the sand within Gastropoda		*						f						f		
For Foraminifera see separate list of those found at Liverpool, Newton, and Dawpool.																

Note.—See Q. J. G. S. vol. xviii. p. 159, "On the Drift containing Recent Shells, in the neighbourhood of Wolverhampton," by Rev. W. Lister, F.G.S. Bushby Junction, in drift, clay and sand—*Nassa reticulata, Turritella terebra, Purpura lapillus, Littorina squalida* (*L. obtusata*, var.), *Astarte borealis, Cardium edule, Tellina balthica*, and *Cyprina islandica*; Oxley Manor, half a mile N.W. of Bushby Junction, Boulder-clay—*Cardium echinatum, Tapes virginea, Venus striata, Mytilus modiolus, Turritella terebra.*

The Mollusca from Dawpool were found by D. Mackintosh, Esq., F.G.S., and myself.

For the list of Mollusca from Lilleshall, Salop, by C. J. Woodward, Esq., see Brit. Assoc. Report, 1865; see also George Maw, Esq., F.L.S., F.G.S., "On the Drift of the Severn Valley," Quart. Journ. Geol. Soc. vol. ii. p. 130; and for the Warrington list, Mr. Paterson, Proc. Warrington Lit. & Phil. Soc.

Mr. De Rance has classed all Mr. Reade's Liverpool localities as Lower Boulder-clay. I have not presumed to alter this; but as Mr. Reade, in his list (Quart. Journ. Geol. Soc. vol. xxx. p. 27), has distinguished the shells from the Upper and Lower Boulder-clays of Liverpool, I have marked them U for Upper and L for Lower Boulder-clay, as they are stated by Mr. Reade to occur.

Prof. Hughes has found the following Mollusca in the Upper Boulder-clay of Denbighshire (Brynclwy—The Mount, St. Asaph):—

Turritella terebra.
Littorina litorea.
Dentalium striolatum.
Pleurotoma turricula.
Tellina Balthica.
Cardium echinatum.
—— edule.
Venus exoleta.
Astarte borealis.

Mr. J. F. Bateman, F.R.S., found some Mollusca in Boulder-clay on the site of the Manchester Waterworks, Hollingsworth Reservoir, Mottram in Longdendale, Cheshire, 568 feet above the sea. Mr. Binney, F.R.S., states that the following were the species found:— *Turritella terebra*, *Trophon clathratus* var. *truncata*, *Purpura lapillus*, *Tellina*, 2 sp., *Cardium edule*, and *Cyprina islandica*.

Discussion.

Dr. Gwyn Jeffreys remarked on the interest attaching to the collections made by Mr. Shone, the most important series of such fossils that had been brought together since Mr. Trimmer and Mr. Darbishire worked out the deposits at Moel Tryfaen and Macclesfield. The mixture of the northern and southern species was very noticeable, and would seem to indicate that some of the beds were *remaniés*. *Venus chione* and *Arca lactea* are peculiarly southern forms, and yet they occur with others which are found only in so-called glacial deposits. Of the latter those found in Cheshire are of Scandinavian and not truly Arctic type. On the other hand the fossils from most of the Scandinavian Posttertiary beds are peculiarly Arctic species, but do not occur in these West-Anglian beds.

Prof. Ramsay, referring to the section, said that he could not help feeling that these deposits only mark minor phases in a great Glacial epoch. It seemed to him that the presence of shells in the Boulder-clays was strongly opposed to the hypothesis according to which these clays represented a deep moraine, and in favour of the marine origin of the deposits. He asked the author whether he believed that, before the deposition of the beds described, the region had undergone extensive erosion by the agency of a great sheet of ice (he did not mean an ice-cap) coming from the north. He was led to the conclusion that such had been the case by the direction of the glacial scratches in the north of England, which are all approximately N. and S., or more or less towards the mountains of Cumberland. This glaciation was followed by a submergence, during which the Boulder-clays were formed.

Prof. Hughes had been over the ground with Mr. Shone, and testified to the accuracy of his work and the great value of his paper. One inference he was inclined to question, viz. the age of the upper part of the series, which Prof. Hughes considered entirely Postglacial. He explained all the scratched stones and some of the northern shells in the so-called Upper Boulder-clay of N. Wales and the borders by their having been derived from older glacial beds.

Mr. Belt considered the paper clear, concise, and to the point. Mr. Tiddeman and others had shown that the ice was piled up to the height of 2000 feet above the sea in Lancashire; Prof. Ramsay that it had overridden Anglesey from the north. It could not have moved down nearly parallel to the coast unless the Irish Sea was filled with ice. This ice had left behind it stones from Cumberland and Scotland; along with these and other transported rocks were broken and worn shells, all of which, it was admitted, had not lived where they were now found, but had been brought from some other place. He contended that the same agent that had brought the foreign rocks had brought also the broken shells and mixed together southern and northern species and deep- and shallow-water forms. He said that in America the ice had not only carried up crystalline rocks thousands of feet above their parent bed, but also soft shales; and if it could do this, it could also carry up sea-shells. He referred to the opinion of Prof. Edward Forbes, who had carefully examined the shells in the northern drift, with the object of determining whether they indicated an ancient sea-coast or an ancient sea-bottom, and had come to the conclusion that they did not, but had been transported to their present position from lower levels.

Dr. J. Gwyn Jeffreys inquired as to the height above the sea-level at which these fossiliferous beds were found, and remarked that our notions of deep-sea forms had changed since the time of Edward Forbes.

The Author, in reply to Prof. Ramsay, remarked that the question raised by him as to whether the rock-striations on low grounds were produced by an ice-sheet or not was a very large one. The softness of the rock in Cheshire would seem to account for no striations being found near Chester; but no doubt such markings are older than the oldest deposits referred to in the paper. In reply to Prof. Hughes, he said that the derivation of the Upper Boulder-clay from the Lower Boulder-clay was barely possible; for, as a rule, beneath the Upper Clay there are usually sands and gravels, and the Scandinavian shells must have passed through the Middle Sands and Gravels in order to get from the Lower into the Upper Boulder-clay. The Upper Clay no doubt indicated an ebbing out of Glacial conditions; but still at the base there is a Scandinavian fauna associated with glaciated stones. In reply to Dr. Jeffreys, he stated that the Newton section is situated at about 140 feet above the sea, and at a distance from it of 20 miles. To Mr. Belt he replied that, as Dr. Jeffreys had said, what the late Edward Forbes would have called "deep-sea forms" would not be so regarded now; all the Mollusca and also the Microzoa from these Drift deposits are either littoral or sublittoral species. The shells containing Microzoa also contain very fine silt, which will come out of them even as they fall through the water in a tumbler into which they have been dropped, so that they could not have borne transportation in their present condition. During their descent from the ground-ice, their contents were probably hard frozen within the shells, which would preserve for a time the silt within them from thawing.

23. *Notes on a* Crocodilian Jaw *from the* Corallian Rocks *of* Weymouth. By E. Tulley Newton, Esq., F.G.S., of H.M. Geological Survey. (Read February 6, 1878.)

[Plate XVI.]

Crocodilian remains from the Corallian Rocks are so rarely to be obtained, that neither in the British Museum nor in the collection of the Geological Survey in Jermyn Street are there to be found more than a few isolated teeth from this horizon. Such being the case, I was led to attach some little importance to the discovery of the remains of a Crocodilian (?) jaw in the beds of this age at Weymouth; and as the specimen possessed certain peculiarities, it seemed desirable that some notice of it should be placed upon record. I have therefore ventured to lay before the members of this Society the following description of the fossil.

The general appearance of the specimen, which I believe to be a portion of a lower jaw, is shown in figure 1; it measures about 11 inches in length. Its present dilapidated condition is due partly to weathering before it was discovered, and partly to the friable nature of both the bone and the matrix, which added much to the difficulty of detaching it from the mass of rock in which it was imbedded. When first found, the upper or alveolar margins were imbedded in the matrix, and the lower parts had been so far denuded as to expose the alveolar cavities, and in some of the anterior ones parts of the teeth were still to be seen. A considerable part of the hinder end of the jaw is wanting. The right ramus has been broken across at *c*, and is thrown about a quarter of an inch outwards from its natural position. So much of this ramus as is preserved contains the remains of twelve alveoli; the anterior one, which is nearly obliterated, passes almost directly forwards and is close to the symphysis, showing clearly that the tooth which it contained was the anterior one of this side of the jaw. A fragment of this tooth is still preserved, but not sufficient to enable one to judge of its original size. The 2nd, 4th, and 5th alveoli also contain portions of teeth, which, it is evident, were naturally directed very obliquely outwards and forwards. The remaining seven alveoli are smaller and have all lost their teeth.

The left ramus is so far broken away as to leave only the 1st and 2nd alveoli: but there are the remains of twelve or thirteen others; so that there is direct evidence of its having possessed fourteen or fifteen teeth. Parts of the 3rd, 4th, and 5th teeth are still retained in their sockets. The fragments of bone lying behind and in the general direction of the right ramus are probably broken pieces of one or more of the other elements of the jaw.

The fragile nature of the specimen rendered it very hazardous to attempt to clear away the matrix from the upper surface; but this having been accomplished, the trouble expended upon it was repaid by the peculiar characters of its front end, which were thereby displayed. The fracture and displacement of the right ramus is shown also in this view (fig. 2). The superior size of the 2nd, 3rd, 4th, and 5th alveoli is well seen, as well as the remains of teeth which several of them contain. In order, apparently, to accommodate these larger teeth, the jaw is wider in this region than in that which is immediately behind it, where the alveoli are smaller. On each side, just within the large alveoli, there is a deep groove, extending from the front backwards to the fifth or sixth tooth. The inner edge of the alveolar border in this region is on a level with the median area of the jaw, as shown by a transverse section, figure 3, while its outer edge is depressed, so that the general plane of this border forms an angle of about 15° with that of the median area. Behind the fifth tooth, the alveolar border, while retaining the same general direction, becomes rapidly lowered until its inner edge is on a level with the bottom of the groove, so that the groove having lost one of its sides, becomes a kind of step, and a transverse section in this region has the appearance shown in figure 4. The median area is almost flat, each half, however, being slightly rounded. The most remarkable peculiarity of this jaw is the manner in which about two inches of the anterior part of the median area becomes separated from the hinder portion, in the form of a spindle, by deep oblique grooves. These grooves pass from the lateral ones opposite the third pair of teeth, and meeting in the middle line dip down into the substance of the jaw or, rather, into a channel which appears to have existed in the symphysis. The spindle-shaped area is longitudinally grooved; whilst the area immediately behind the oblique grooves, although somewhat broken, gives evidence of having possessed a longitudinal ridge close to the symphysial suture.

The teeth are fragmentary; but still, from what remains of them, several of their characters may be made out. Allusion has already been made to the fact that the 2nd, 3rd, 4th, and 5th teeth upon each side are larger than the others. In two or three instances the young teeth may be seen within the broken roots of the mature ones. The bases of the largest teeth must have had a diameter of at least half an inch; and, judging from an impression in the matrix, they projected about an inch and a quarter above the margin of the jaw. This impression also shows that there was no very marked division between the crown and the fang of the tooth, the former, however, being distinguished by the possession of fine, but very distinct longitudinal ridges. In transverse section the greater part of the tooth appears to have been circular; but the apex of a young unused tooth which is well preserved in the third alveolus of the left ramus is slightly compressed, having a distinct ridge running down each side, and two smaller ridges on the inner face; a transverse section near the apex would give an outline as in figure 5 *b*.

With regard to the length of the symphysis, one cannot speak with certainty, on account of the parts being displaced; but while it seems extremely probable that it extended at least as far as the seventh tooth, it is tolerably certain that it did not extend beyond the tenth or eleventh tooth. The splenial elements, however, may have formed part of the symphysis, and carried it a little further back.

At present I am unable to refer this jaw to any known genus; and this not because of the imperfection of the specimen, but rather because the peculiar characters which it possesses are not to be found, so far as I am aware, in either of the genera hitherto described. The lenticular area and the oblique grooves by which this is separated from the rest of the median area do not appear to be represented in either of the genera mentioned by M. Deslongchamps *, and certainly they are not shown in any of his figures. *Metriorhynchus*, it is true, has four large teeth in the front of the lower jaw; and supposing that the anterior tooth in our specimen was a small one, then there would be four large teeth here also; but then they do not occupy the same relative positions, for in *Metriorhynchus* it is the first to the fourth teeth which are large, while in our specimen it would be the second to the fifth. It is quite possible that the anterior tooth in this specimen was large also. The depth of the lateral grooves, especially towards the front, and the presence of the oblique grooves are likewise very marked characters, and the relative proportions of the jaw seem to be equally peculiar.

The specimen forming the subject of this communication I obtained from a mass of rock which had fallen from one of the uppermost beds of the Corallian Rocks west of Sandsfoot Castle, Weymouth, at the point where the road ends upon the shore. The rock itself is a greenish-brown, sandy grit, and appears to belong to the bed 3 of Messrs. Blake and Hudleston's section of the Sandsfoot-Castle Beds †.

In the same block were also found two shells, which my esteemed colleague Mr. Etheridge agrees with me in referring to *Goniomya literata* and *Pinna lanceolata*.

DESCRIPTION OF PLATE XVI.

(Figs. 1–4 one half natural size.)

Fig. 1. Crocodilian lower jaw from the Corallian of Weymouth; seen from below, the upper surface being imbedded in the matrix and the lower portions denuded so as to expose the alveoli.
Fig. 2. Same specimen, front part seen from above.
Fig. 3. Transverse section at *a* in fig. 2.
Fig. 4. Ditto at *b* in ditto.
Fig. 5. Crown of young tooth preserved in the third alveolus of the left ramus; view of outer surface.
5*a*. Side view of apex of same tooth.
5*b*. Transverse section of ditto a short distance from apex.
Fig. 6. Tooth restored from several portions.

* Notes Paléontologiques, vol. i.
† Quart. Journ. Geol. Soc. vol. xxxiii. p. 270.

Fig. 1.

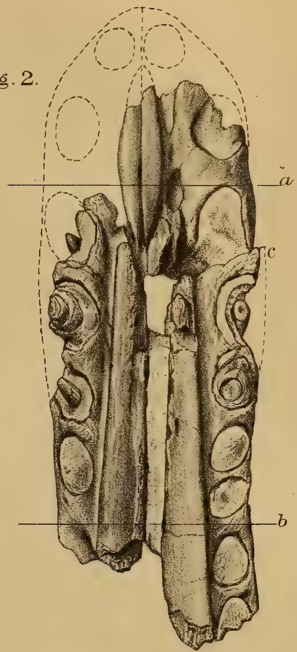


Fig. 2.

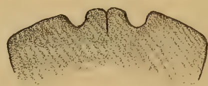


Fig. 3.

Fig. 4.

5a.
5b.

Fig. 5.

Fig. 6.

C. L. Griesbach lith.

Mintern Bros imp.

CORALLIAN CROCODILE.

Discussion.

Prof. Seeley remarked that, so far as he could judge from a hasty inspection of the supposed Crocodilian jaw from the Coral Rag, he should be disposed to regard the specimen as Plesiosaurian. The somewhat Plesiosaurian modifications which it presented were such as are met with in the jaws of Plesiosaurs from the Oxford Clay.

The Author in reply expressed his doubts as to this notion, but at the same time reminded the meeting that on account of the uncertainty which existed he had refrained from referring the specimen to any particular genus.

24. CONTRIBUTIONS *to the* HISTORY *of the* DEER *of the* EUROPEAN MIOCENE *and* PLIOCENE STRATA. By W. BOYD DAWKINS, Esq., M.A., F.R.S., F.G.S., Professor of Geology and Palæontology in the Owens College. (Read December 19, 1877.)

CONTENTS.

I. INTRODUCTION.

THE Deer of the European Miocene and Pliocene strata have hitherto been a stumbling-block in the path of the palæontologist, from the fragmentary condition in which their antlers are generally preserved, and the difficulty of separating their variations in form, dependent on age, from those which are worthy to rank as of specific value. They are represented, for the most part, by local names without definitions, which in many cases are synonyms so complicated, that very generally I have found it necessary to examine the original specimen before arriving at an opinion as to their value. To add to the confusion, MM. Croizet and Jobert published their work on the Pliocene Cervidæ of Auvergne * without letterpress, and with the names only of the species printed on the outer coloured cover of each part, which, in the natural course of things, has been rejected by the binder. I have only met with them in one out of the many copies which I have seen, in the Jardin des Plantes in Paris. The work of M. Pomel is without plates †, and that projected by that author and M. Bravard (which included the Cervidæ) was never published.

In the following essay, based upon materials collected from time to time in France and Italy, I have defined some of those forms of Deer which are most widely spread and most perfectly preserved, confining my attention solely to the antlers. I have merely attempted to treat a portion of the subject, reserving the rest until

* Les Oss. foss. du Dép. du Puy-de-Dôme, 4to, 1828.

† Cat. Méthodique des Vertébrés Fossiles du Bassin Sup. de la Loire (Paris, 1854).

new evidence may be brought forward about the numerous other species which are only known to me by obscure fragments.

II. Classification.

The antlers defined in the following pages may conveniently be grouped together under the head of (1) Capreoli, or Roe-like, (2) Axeidæ or Eastern Deer, of the type of the *Axis* and *Rusa*, and (3) Deer *incertæ sedis*, which I am unable to bring into close relation with any living forms. They are represented by the following species:—

	Name.		Formation.
1. Capreoli.	1. *Dicroceros elegans*,	Lartet.	Middle Miocene.
	=*Prox furcatus*,	Hensel.	Miocene.
	2. *Cervus dicranoceros*,	Kaup.	Upper Miocene.
	=*C. anoceros*,	,,	
	=*C. trigonoceros*,	,,	
	3. *C. australis*,	De Serres.	Lower Pliocene.
	4. *C. Matheroni*,	Gervais.	Upper Miocene.
	=*C. Bravardi*,	Bravard, MS.	
	5. *C. cusanus*,	Croizet and Jobert.	Pliocene.
2. Axeidæ ...	6. *Cervus perrieri*,	Croizet and Jobert.	Upper Pliocene.
	=*C. issiodorensis*,	,,	
	=*C. pardinensis*,	,,	
	7. *C. etueriarum*,	,,	,,
	=*C. rusoides*,	Pomel.	
	=*C. perollensis*,	Bravard.	
	=*C. stylodus*,	,,	,,
	8. *C. suttonensis*,	Dawkins.	Pliocene.
	9. *C. cylindroceros*,	,,	Upper Pliocene.
	=*C. gracilis*,	,,	
3. Incertæ sedis.	10. *C. tetraceros*,	Dawkins.	Upper Pliocene.

III. The Capreoli.

A. *Dicroceros elegans*, *Cervus dicranoceros*, *C. australis*.

The Deer comprised under this head possess antlers similar to those of the living Muntjak (*Cervulus*) and Roe (*Capreolus*), which are short, round, and generally perched on a long pedicle. The crown is either simply forked or composed of short confluent tynes.

The first antler-bearing Deer which appears in the geological record is the *Dicroceros elegans* (Lartet)* of the Middle Miocene of Sansan and Simorre, in which the antler is composed of a simple fork springing close to the burr, and crowning the summit of a long and slender pedicle like that of the Muntjak. Similar antlers have been met with in the Canton of St. Donnat (Brome) and La Grive, St. Albans (Isère), and are preserved in the geological collection in the

* Lartet, 'Notice sur la Colline de Sansan,' p. 34; 'Comptes Rendus,' t. iv. p. 88, and t. v. p. 131.

Palais des Beaux Arts at Lyons, under the care of my friend Dr. Lortet. In Germany the same form may be recognized under the name of *Prox furcatus* of Hensel, from the Miocene of Steinheim.

The simple bifurcating type of antler is met with also in the Upper Miocenes of Eppelsheim, considered by Prof. Gaudry to be older than those of Mont Léberon and Cucuron, in the Deer named by Dr. Kaup * *C. anoceros* and *C. dicranoceros,* which seems to me to be an older variety of the same form. In these the fork of the antler is further removed from the burr than in the *Dicroceros elegans*, and is so far therefore more differentiated. Closely allied to them is the *Cervus australis* of De Serres †, from the Lower Pliocene strata of Montpellier, which is the last fossil representative of Deer of this peculiar type in the European Tertiaries.

The difference between these antlers is so very slight that I feel inclined to view their possessors as homologous species, using the term so happily employed by Dr. Heer to denote a lineal ancestry. In the *Dicroceros* of the Middle Miocenes we find the antler at a minimum of development, consisting merely of a forked crown springing directly from the burr, while in the Deer of the Upper Miocene the forked crown is separated from the burr by a short beam; and this form is repeated in the Lower Pliocene *C. australis.* The Middle Miocene type is preserved among the existing Deer by the Muntjak, or *Cervulus,* of the oriental region of Asia.

B. *Cervus Matheroni* (Gervais). (Fig. 1.)

C. Matheroni, Gervais, Paléont. 1859, p. 149; Gaudry, Animaux fossiles de Mont Léberon, 4to, p. 65, pl. 13.

C. Bravardi, Brit. Mus. Cat. no. 34623.

The *Cervus Matheroni* of the Upper Miocenes of Cucuron and Mont Léberon is considered by Profs. Gervais and Gaudry to belong to the same division of round-antlered Deer as the *Axis.* It is, however, certain, from the examination of the nearly perfect antlers (fig. 1) in the British Museum, and their comparison with those figured by Prof. Gaudry, that its affinities are rather with the Capreoli. The specimen termed *C. Bravardi* in the British Museum is the type selected for publication by MM. Pomel and Bravard in a work which, unfortunately, still remains unpublished.

Definition.—The characters of the two antlers (fig. 1), which belong to the same individual, are as follows:—Pedicle moderate, round; antler erect, deeply grooved, four-pointed at most; burr (A) at right angles to long axis of antler and stout; second tyne, D, given off nearly at right angles to beam, oval, waved, upturned at tip; third tyne, E, upturned, round, and at acute angles to beam; crown, CF, small and two-pointed, palmated.

* Kaup, 'Les Oss. foss. de Darmstadt;' and Karsten, 'Archiv für Mineralogie,' vi. p. 217.

† Gervais, Paléont. p. 151, pl. vii. fig. 1; Marcel des Serres, 'Cav. de Lunel-Viel,' p. 230.

The only differences to be observed between these antlers and those figured and described by Prof. Gaudry are that in the latter the second tyne rises at a smaller angle to the beam, and the third is larger. These are probably due to varying age and possibly race.

Fig. 1.

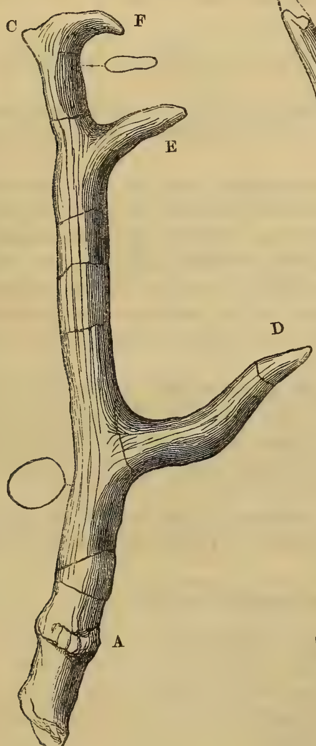


Fig. 2.

Fig. 1. Antler of *Cervus Matheroni*, Gerv., Brit. Mus., one third nat. size.
Fig. 2. Antler of *Cervus cusanus,* Cr. & Job., Brit. Mus., one third nat. size.

The absence of the brow-tyne (see B, figs. 3–5) separates this type of antler from that of the division *Axis* and *Rusa*, with which it has been compared.

Size.—The head of the animal was about the size of that of a large Roe-deer, which it probably resembled in outer form.

Measurements (*inches*).

	Brit. Mus.	Gaudry.
Extreme length from burr to crown . .	11·4	
Length of pedicle	1·5	1·2
Basal circumference above burr	2·8	
From burr to second tyne	3·0	4·75
Length of second tyne	3·0	
From second to third tyne	4·2	3·9

Formation.—Upper Miocenes of Cucuron and Mont Léberon.

C. *Cervus cusanus*, Croizet and Jobert. (Fig. 2.)

Cervus cusanus, Croizet and Jobert, Les Oss. foss. de Puy-de-Dôme, 4to, pl. viii.; Pomel, Cat. Méthodique, p. 111; Gervais, Paléont. p. 149.

The antlers of this Pliocene species belong to the same round-antlered division as the Roe-deer or Capreoli, and are so closely allied to those of the *Cervus Matheroni* of the Upper Miocenes that the latter species may have been the ancestor of the former. The antler in the British Museum (No. 34610) from the Pliocene strata of Ardé in Le Puy belongs obviously to the same species as that figured but not described by Croizet and Jobert from Mont Perrier near Issoire.

Definition (fig. 2).—Pedicle long, round; antler rounded below, grooved, erect, three-tyned; burr, A, at right angles to long axis of antler and stout; beam flattened as it approaches second tyne, D; second tyne at acute angles to beam, oval, flattened, pointed; crown composed of two flattened tynes, C, E; no brow-tyne.

These characters, in the specimen in the British Museum, are repeated with but little modification in that figured by MM. Croizet and Jobert.

Measurements (inches).

Extreme length of specimen	12·0
Length of pedicle	1·5
Basal circumference above burr	2·6
From burr to second tyne	4·4
Length of second tyne	1·7

Relation to Roe-deer.—The animal was probably about the size of a Roe-deer, from which it differed in the antlers being longer and more slender, and having the channelled beam free from knobs. In general form the antlers resemble the third antlers of the Roe *, and bear to them the same relation as those of *Dicroceros* to those of the Muntjak. It seems therefore to me almost certain that the *Cervus cusanus* was the lineal ancestor of the Roe, which makes its first appearance in the forest-bed of Norfolk, and that through it the

* See Blasius, 'Säugethiere Deutschlands,' p. 463.

Capreoline type may be traced back to the *Cervus Matheroni* of the Upper Miocenes.

From the description of *Cervus Cauvieri* given by Prof. Gervais, I should infer that it is closely allied to, if not identical with, *C. cusanus*.

Formation.—Pliocenes of Cuyssac, near Le Puy (Haute Loire), Ardé, and Etuaire, near Issoire.

IV. The Axeidæ.

The fossil species grouped together under this head consist of forms closely allied to the round-antlered Deer of the Oriental Region of Mr. Wallace, which possess one brow-tyne and two or three other tynes, such as the Axis, Rusa, *Cervus taëvanus*, and *C. mantchuricus*.

A. *Cervus perrieri*. (Figs. 3 & 4.)

Cervus perrieri, Croizet and Jobert, *op. cit.* pls. iv., v., vi., viii. figs. 9, 10; Pomel, Cat. Méthod. p. 104.

C. issiodorensis, Pomel, Cat. Méthod. p. 105; Gervais, Paléont. p. 147.

The type specimens of the two forms of Deer from Mont Perrier, described under the name of *C. perrieri*, are preserved in the Jardin des Plantes at Paris, and are sufficiently perfect to offer a basis for defining one species at least of the Pliocene Cervidæ, which hitherto, owing to the unfortunate accident, before alluded to, of Messrs. Croizet and Jobert's figures of the Cervidæ being without descriptions, have been very imperfectly known.

Definition.—A splendid frontlet bearing two antlers nearly perfect offers the following characters:—Antler (fig. 3) round, grooved, and possessed of four tynes—a brow, B, and a second, D, and two terminal, C, E, which form a fork; pedicle short; burr, A, stout and nearly at right angles to beam; brow-tyne round, given off close to burr, nearly at right angles; beam nearly straight between brow-tyne and second tyne, flattened at basement of latter, thence it sweeps backwards to basement of tyne E, which, with tyne C, constitutes the crown; tynes D, C, and E are round, and form acute angles with the beam, the angle being more open in the case of D than of C and E.

On comparing this antler with that of *Cervus issiodorensis* (fig. 4) in the same Museum the above definition applies with but slight modifications, which are usually met with in antlers belonging to the same species. In the latter the grooves are not so deep; there is a web, or process of antler, at the interspace between the brow-tyne, B, and the beam; the second tyne, D, is set on at a slightly sharper angle, and the beam forms two gentle curvatures, which are not so strong as in the antler of *C. perrieri*.

Measurements (inches).

	C. perrieri.	*C. issiodorensis.*
Total length from burr	31·0	32·0
Length of pedicle..............	1·8	
Circumference of pedicle	5·8	
Basal circumference of antler	5·8	6·3
Distance of brow-tyne from burr..	0·8	
Circumference of brow-tyne	3·9	
Brow-tyne to second tyne	13·0	12·0
Second tyne to third	7·5	9·0
Basal measurement of second tyne	..	4·25

Fig. 6. Fig. 5. Fig. 3. Fig. 4.

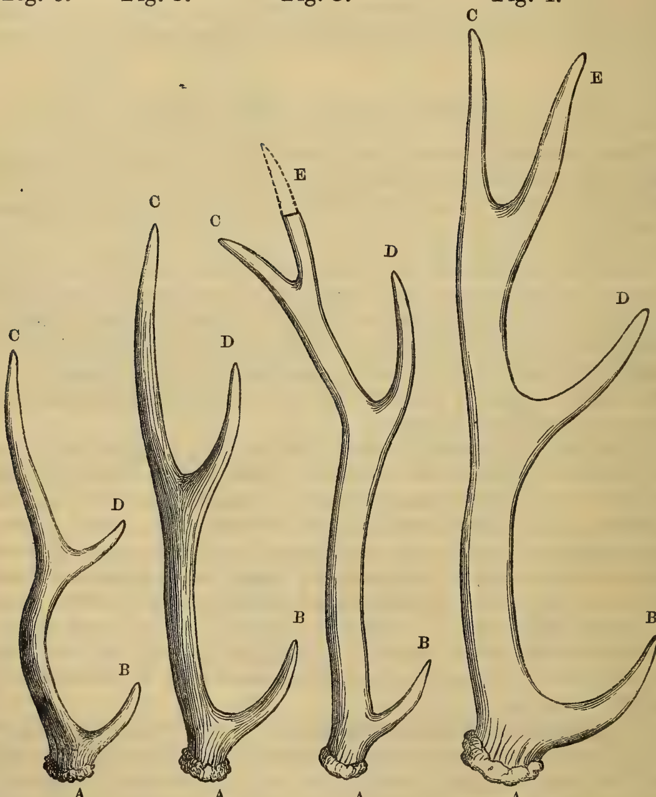


Fig. 3. Antler of *Cervus perrieri*, Cr. & Job. (Jardin des Plantes, Paris), one ninth nat. size.

Fig. 4. Antler of *Cervus issiodorensis*, Pomel (Jardin des Plantes, Paris), one eighth nat. size.

Fig. 5. Antler of *Cervus pardinensis*, Cr. & Job. (Jardin des Plantes, Paris), one ninth nat. size.

Fig. 6. Antler of *Cervus etueriarum*, Cr. & Job. (Jardin des Plantes, Paris), one ninth nat. size.

It will be seen from this description and the measurements that these two so-called species are really merely individual variations of one species, for which I would retain the name of *C. perrieri*.

I detected antlers belonging to this species preserved in the collection (examined in 1866) of Mr. Dowson at Beccles, Suffolk, comprising basal and coronal parts, one of the former being identical with the variety *C. issiodorensis*. The locality, however, of these fragments is uncertain, and it is just as likely that they may have been derived from the Pliocenes of France as from the same horizon in the Crags of Norfolk and Suffolk.

A perfect antler with four tynes, in the Museum at Florence, obtained from the Val d'Arno, which I examined in 1877, also belongs to this form, which therefore is common to the Pliocenes of France and Italy.

Living Representative.—This peculiar type of antler, with four tynes, is identical in form with that of the *Cervus taëvanus* of the island of Formosa, which Dr. Sclater has figured and described from the animals living in the Gardens of the Zoological Society in Regent's Park (Zool. Trans. 1870, p. 345, pls. xxxiii., xxxiv.). It is also identical with that of *Cervus mantchuricus* figured and described by Dr. Sclater in the same essay (= *Pseudaxis mantchuricus* of British Museum Catalogue, which relates to a young animal with a three-tyned antler).

B. *Cervus pardinensis.*

Cervus pardinensis, Croizet and Jobert, *op. cit.* pl. xi; Pomel, *op. cit.* p. 106; Gervais, *op. cit.* p. 140.

The type specimen bearing this name is in the Jardin des Plantes in Paris, and consists of a shed antler, perfect with the exception of the tips of the three tynes, from Pardines, Mont Perrier.

Definition.—It possesses the following characters:—Antler (fig. 5) grooved, round, but slightly curved, and possessed of three tynes; burr (A) stout and oblique to long axis of beam; brow-tyne (B) basal, short, round, and springing at an acute angle; brow-tyne angle webbed; second tyne (D) forming a forked crown, smaller than third, which it joins at an acute angle; coronal angle webbed.

Measurements (inches).

	C. pardinensis (Jardin des Plantes, 1874).
Total length from burr	22·0
Circumference of base of antler	4·7
Burr to fork	2·8
Brow-tyne to coronal fork	11·0

This form of antler seems to me to be closely related to that of *Cervus perrieri*, and it is very possible that it is a younger antler of that species, related to it as the young *Cervus* (*Pseudaxis* of Gray) *mantchuricus* in the British Museum with three tynes is related to the older animal with four tynes figured by Dr. Sclater, and living in the Zoological Gardens, London, in 1870. It is evident, from the history of antler-development in the round-antlered Deer, that *Cervus perrieri* must have had an antler with two and three tynes before it arrived at the number of four, or just such an antler as this in question. For these reasons, and although the brow-tyne is set on at a smaller angle than in the type specimen of *Cervus perrieri*, I feel inclined to view *C. pardinensis* as a variety and not a distinct species. All these three antlers (figs. 3–5) are found in the same Pliocene strata at Mont Perrier. Nevertheless it must not be forgotten that Deer of the Axis and Rusa type possessing this form of three-tyned antler live in the Oriental Region along with those possessing four-tyned antlers, *C. taëvanus* and *C. mantchuricus*, and that therefore it is possible that *C. pardinensis* may be a distinct species from *C. perrieri*. For this reason the name is retained in this contribution to the history of the Cervidæ.

C. *Cervus etueriarum*, Croizet and Jobert. (Fig. 6.)

Cervus etueriarum, Croizet and Jobert, *op. cit.* pl. vi. figs. 1 & 2, and pls. vii. & viii.; Gervais, *op. cit.* p. 148.
C. rusoides, Pomel, *op. cit.* p. 106.
C. stylodus, Bravard, MSS. No. 182.
C. peyrollensis, Bravard, MSS.

The antlers (including one of the typical specimens of Croizet and Jobert preserved in the Museum of the Jardin des Plantes at Paris, and referable to the above species or form) are all small, and are as closely allied to *Cervus pardinensis* as the Axis is to the Rusa. It is, however, safer, in the present imperfect state of our knowledge, to keep them separate.

Definition.—Antlers (fig. 6) possessed of a graceful double curvature, and with three tynes; grooved basally; burr at right angles to long axis of pedicle; pedicle short; brow-tyne (B) set on at an acute angle, which approaches in some specimens a right angle, round; second tyne (D) round; fork of crown webbed, acute-angled in some, right-angled in others.

The antlers which possess these characters I have met with in the Jardin des Plantes from Mont Perrier, and from the Pliocenes of the Val d'Arno, from which place those in the British Museum (Nos. 28833 & 28834) were obtained by Mr. Pentland. I have also observed the same form in the Museum at Lyons in 1873 from Chagny (Saône et Loire), as well as in the Museum at Florence.

The series of antlers in the British Museum obtained from Peyrolles by M. Bravard, and named *Cervus peyrollensis* and *C. stylodus*, are undistinguishable from those of *C. etueriarum* (Nos. 34516 and 34521, 3, 6, 7, 8 of the Museum Catalogue).

Living Representative.—The *Cervus etueriarum* is closely allied to the Axis, Chetul, or Spotted Deer of India, some varieties of which possess antlers (Brit. Mus.) of the same slender form and double curvature.

Measurements (inches).

	Jardin des Plantes, Mont Perrier.	Palais des Beaux Arts, Lyons, Chagny (Saône et Loire).	Jardin des Plantes, Paris; Val d'Arno.	Ditto.	Ditto. Brit. Mus. Coll., Pentland, 28833.	*C. peyrollensis*, Brit. Mus., No. 34516.	Ditto, No. 34526.	Ditto, No. 34527.
Total length	21+	9+	...	...	...	...	11+	
Length of pedicle........................	1·5							
Circumference of pedicle................	3·8							
Basal circumference of antler........	4·5	3·9	3·9	4·0	3·5	4·5	3·4	2·8
Burr to fork of brow-tyne	2·0	1·5	1·15	1·8	1·4	2·4	2·5	1·5
Fork of brow-tyne to fork of second tyne......................	9·5	6·0	...	...	8·0			
Length of third tyne	10·0							

Formation.—Upper Pliocenes of Auvergne, Chagny, and the Val d'Arno.

D. *Cervus suttonensis*, Dawkins. (Figs. 7, 8, 9, 10.)

A series of antlers in the British Museum from the Crag presents characters which I am unable to identify with those of any species on record, and which I have met with in nearly every collection of Mammalia from the Crag in Norfolk and Suffolk which I have examined. In spite, therefore, of their fragmentary condition, I have ventured to figure and describe them under the name of *Cervus suttonensis*, because the two most perfect examples were obtained from the Crag of Sutton. Three out of the four antlers chosen as types are in the British Museum, and are more or less waterworn and stained with peroxide of iron, like most of the remains of the Mammalia with which they were associated. All those which I have seen have been shed, and not torn forcibly away from the head; and all have lost the crown and the distal portion of the beam. The specimens in the British Museum have been obtained at Sutton, Felixstowe, and Woodbridge. Those communicated by Mr. Ransome to Professor Owen, and assigned by him to the Miocene *Cervus dicranoceros* of Kaup, were derived from the Red Crag of Sutton and Ipswich; those in Mr. Whincopp's collection from that of Woodbridge; those in the Rev. J. Gunn's from the Norwich Crag of Horstead; and those in Mr. Prestwich's from Sutton.

Definition (figs. 7–10).—The base of the antler is cylindrical, and the burr is very strongly marked and circumscribes the base in a plane

Fig. 7.

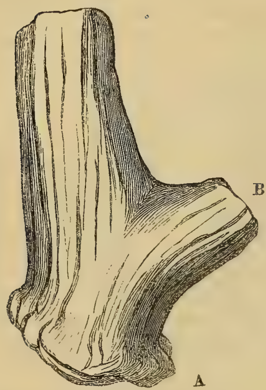


Fig. 8.

Fig. 9.

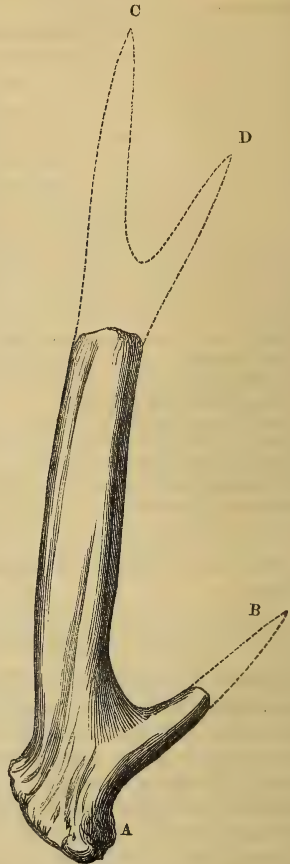


Fig. 10.

Figs. 7–9. Antler of *Cervus suttonensis*, Dawkins, Sutton (Brit. Mus.), one half nat. size.

Fig. 10. Simple antler of *Cervus suttonensis*, Dawkins, Woodbridge (Coll. Whincopp), one half nat. size.

oblique to the axis of the beam, which is traversed by clearly defined deep grooves. These, however, are very generally worn away by the action of water. The beam runs straight away from the burr and is cylindrical, except at the point where the brow-tyne springs immediately above the base. At that point there is a smooth triangular area, slightly convex or flat on the superior surface and slightly concave on the inferior, and which is free from the grooves which occur on the rest of the antler. The brow-tyne (B) is slightly oval in section, and gradually tapers to a rounded point, which is broken away in all the specimens which have passed through my hands; it forms an acute angle with the beam, as in *Axis* and *Rusa*, and is very much smaller in every dimension. The beam in figs. 8 & 9 is flattened at the point H on its superior surface, which is an indication that a tyne was about to take its rise. The flattening cannot be a mere accidental variation, because it is found in all the antlers which present 4 or 5 inches of beam. Direct evidence as to the crown is wanting; but the fact that all the antlers (some twenty-six or thirty) are broken in some part of the beam, implies that they possessed a crown which was not simple *, and the median flattening renders it very probable that it was forked, as in *Axis* and *Rusa*. A fragment of a crown of two points, from the Crag of Sutton, in the possession of Mr. Prestwich, may perhaps be assigned to this species. On the whole, the scanty evidence points in the direction of the Axis and Rusa rather than in any other.

In Mr. Whincopp's collection, which I examined at Woodbridge in 1866, is a nearly perfect specimen of a simple styliform antler, about 3 inches long, shed and deeply grooved (fig. 10). It is probably the first young antler of this species. It was accompanied by two fragments of similar form.

Two small waterworn fragments of the base of the antler of *Cervus suttonensis* have been referred by Prof. Owen to the *Cervus dicranoceros* of Kaup from the Miocene of Darmstadt. If, however, Prof. Owen's figures in the 'Quarterly Journal of the Geological Society' (vol. vii. p. 234, figs. 14*a*, 16) be compared with those of Dr. Kaup (Oss. foss. de Darmstadt, tab. 24. figs. 3, 3*e*), it will be seen that the former antler, which is very much waterworn, possesses a beam (*op. cit.* fig. 14*a*) which is much larger than the simple bifurcated antler of *C. dicranoceros* described by Dr. Kaup †.

In *C. dicranoceros* the beam and the brow-tyne were equal in length or nearly so, while in the series of antlers of *C. suttonensis* the beam was at least as well developed as in Axis and Rusa, and bore a crown. For the same reason also the series of antlers cannot be referred to the *C. australis* of Marcel de Serres, from the marine sands of Montpellier.

* The cause of the fracture is the firm fixture of the crown in the stratum while the rest was exposed to the dash of the waves which washed the antlers out of the fluviatile gravel in which they were imbedded.

† Prof. Owen's fig. 16 represents an antler viewed on the underside, and in such perspective that the brow-tyne appears to be of nearly equal size with the beam.

Measurements (inches).

	British Museum.				Whincopp Coll.			Montmerle.
	No. 27516.	No. 28982.	No. 29505.	No. 27858.				
Burr to fork of brow-tyne	1·12	1·6	1·95	1·98	2·4	2·2	1·25	1·0
Circumference above brow-tyne...	2·2	3·0	3·6	3·5				
Length of beam	5·5	5·0	4·0	...	8·0			
Circumference of base...............	3·0	...	4·4	4·4	4·2	3·5	2·6	4·0

This type of antler is met with also in France. A specimen which I identified in the Museum at the Palais des Beaux Arts at Lyons, in 1873, was derived from the Pliocene strata of Montmerle (Aire), which, according to Dr. Lortet, are of the same age as those of Chagny. It is almost identical with fig. 8. This form of Deer, therefore, is common to the Pliocenes of Norfolk, Suffolk, and of Central France.

Affinities.—The *Cervus suttonensis* is, in its general form, closely allied to *C. pardinensis*, of which it may be a small breed or variety; but, considering the fragmentary nature of the specimens referable to it, I think it safe to keep the two series distinct and under different names. It belongs to the section of the Cervidæ now only found in the hot regions of Eastern Asia.

E. *Cervus cylindroceros*, Dawkins. (Figs. 11, 12.)

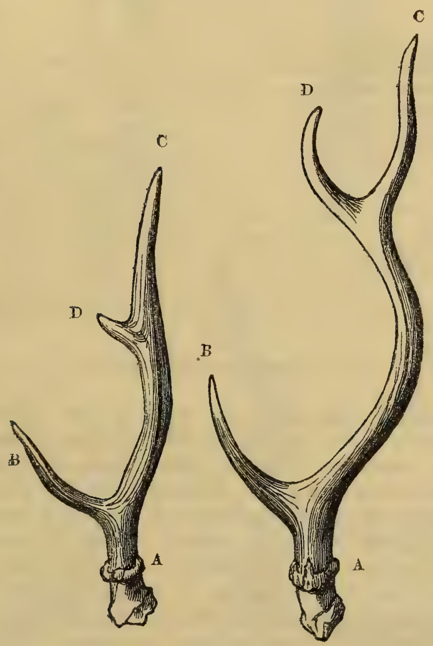
Cervus cylindroceros, Bravard, MSS.
C. gracilis, Bravard, MSS.
? *C. ambiguus*, Pomel, *op. cit.*

The two antlers described under this name were derived from Ardé, Puy de Dôme, and are, so far as I know, without any figures or descriptions, the names merely being those attached to the specimens in the British Museum by their discoverer, M. Bravard. The name is selected because the antler to which it belongs is in a better state of preservation than the other, which is crushed and flattened.

Definition.—The antler of *Cervus cylindroceros* (fig. 11) is, like those of *C. etueriarum*, possessed of three tynes and a sigmoid curve; it is round and grooved. The pedicle is short; burr (A) stout, and nearly at right angles to pedicle; brow-tyne (B) round and rising at a distance from the burr; brow-tyne fork nearly at right angles; second tyne (D) and third (C) with rounded tips; fork between them acute-angled and webbed. The third tyne is longer than the second. These characters are repeated in *C. gracilis* (fig. 12), with the exception that the second antler is very much smaller, and evidently belonged to a younger animal.

These antlers are distinguished from those which have preceded them by the brow-tyne springing at a distance instead of rising directly from the burr.

Fig. 12. Fig. 11.



Figs. 11, 12. Antlers of *Cervus cylindroceros*, Dawkins, Auvergne (Brit. Mus.), one eighth nat. size.

The fragmentary remains which form the type specimens of the *Cervus ardeus* (or *ardei*) of Messrs. Croizet and Jobert, from Ardé, and are preserved in the Jardin des Plantes in Paris, are also referable in part to this species, together with some other specimens bearing the same name. The fragment, however, with two tynes, assigned by Croizet and Jobert (pl. ii. fig. 3, and pl. iii. fig. 2) to this animal, probably belongs to some other species.

It is very likely that the *C. ambiguus* of Pomel, from the Pliocenes of Peyrolles, belongs to this species.

Formation.—Upper Pliocenes of Auvergne.

Measurements (inches).

	Cervus cylindroceros, Brit. Mus.	*C. gracilis.*	*C. ardeus*, Jardin des Plantes.			
Total length from burr	25 *	18·8				
Length of pedicle	1·5	1·1	2·2			
Circumference of pedicle	4·4	...	3·8			
Basal circumference of antler	4·5	2·7	4·2	6·0	5·5	5·3
Burr to brow-tyne	2·0	...	2·5	...	3·2	3·0
Burr to fork	4·5	3·5	4·0	5·5	5·1	5·5
Brow-tyne to second fork	13·5	8·9				
Length of brow-tyne	7·0	6·0				
Length of second tyne	7·5	2·0				
Length of third tyne	9·5	8·0				

V. Deer incertæ sedis.

Cervine antlers have been met with in the Pliocene strata of France and Italy which cannot be brought into close relation with any of those possessed by living Deer: such, for example, as the *Cervus ramosus* from Auvergne in the Jardin des Plantes in Paris, and the magnificent pair of antlers from the Val d'Arno in the Geological Museum at Florence, termed *Cervus dicranios* by Nesti, which has not as yet been accurately determined, and many others, among which the following series of antlers deserves a prominent place from their perfection and their number, and the light they throw on the variation in antler-form in proportion to age.

Cervus tetraceros, Dawkins. (Figs. 13, 14, 15, 16, 17.)

C. tetracroceros, Bravard, MSS.

The seven shed antlers bearing these names in the British Museum were derived from the Pliocene strata of Peyrolles in the Puy de Dôme, and are remarkable not merely from their forms, but for their fine state of preservation.

They possess respectively two, three, and four tynes, and evidently follow the usual rule of the development of tynes in the Cervidæ, in which the first appears in the second year, and the rest *en suite*. They belong therefore to animals four, five, and six years old. The two-year old animal probably possessed a simple styliform antler, while at three years a brow-tyne appeared, as is

* 27 inches, following curvature.

Fig. 14.

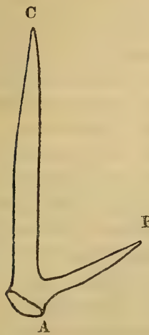


Fig. 13.

Fig. 15.

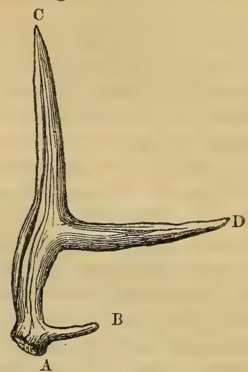


Fig. 16.

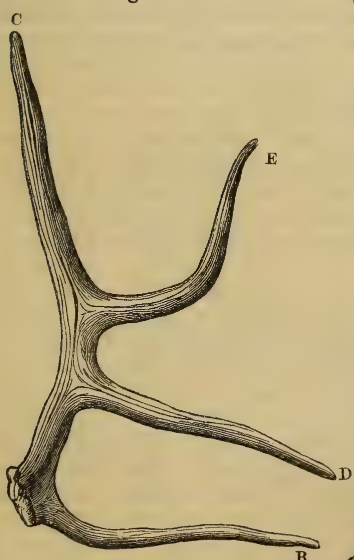
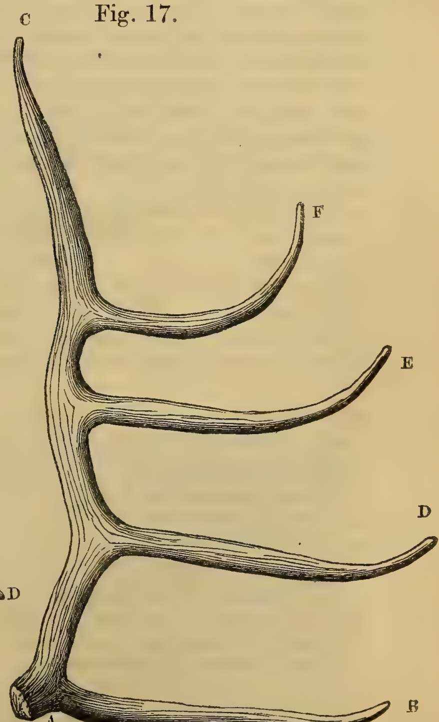


Fig. 17.



Figs. 13, 14. *Cervus tetraceros*, Dawkins, first and second antlers restored.

Fig. 15. Fourth antler of *Cervus tetraceros*, Dawkins, Peyrolles (Brit. Mus.), one eighth nat. size.

Fig. 16. Fifth antler of *Cervus tetraceros*, Dawkins, Peyrolles (Brit. Mus.), one eighth nat. size.

Fig. 17. Sixth antler of *Cervus tetraceros*, Dawkins, Peyrolles (Brit. Mus.), one eighth nat. size.

represented in figs. 13 and 14, which are restorations based upon the antlers 15–17.

Definition.—The antler (fig. 15) of the four-year old possesses the following characters :—Beam (A C) rounded, straight, styliform, channelled; burr (A) oblique to long axis of beam; brow-tyne (B) round, and at rather less than right angles to beam; second tyne (D) round, straight, styliform, at right angles to beam, which is flattened at its point of origin; terminal point (C) rounded, styliform.

In fig. 16 of the five-year old these characters are repeated with slight modifications. The brow-tyne (B) is remarkably long and slender, and springs at a right angle. The third tyne (E) like the second, springs at right angles, but is suddenly reflected at a point 5·4 inches from the beam to terminate in a round point 7·8 inches from the obtuse angle of reflection in the figured specimens. These characters are presented by three antlers. In the antler of six years old (fig. 17) all the tynes spring at right angles to the beam, and the second (D), third (E), and fourth (F) are gently reflected, the curvature being the greatest in the fourth tyne. These characters are presented also by three other antlers.

It will be observed also that there is a progress in size in these three antlers figured, and that the tynes all spring from the upper and outer side of the beam. All also have been more or less crushed and flattened, but evidently belong to the round-antlered section of Deer.

Measurements (inches).

	Four years. Brit. Mus., No. 34405.	Five years. Brit. Mus., No. 34406.	Six years. Brit. Mus., No. 34409.
Total length from burr	15·5	23·0	31·0
Basal circumference of antler			
Length of brow-tyne	...	13·+	16·+
Basal diameter of brow-tyne	0·6	1·1	1·2
Brow-tyne to second tyne	4·0	5·0	6·0
Length of second tyne	7·5	13·0	15·+
Basal diameter of second tyne	1·3	1·2	1·4
Second tyne to third tyne	...	2·6	5·0
Length of third tyne	...	13·2	15·6
Basal diameter of third tyne	...	1·3	1·4
Third tyne to fourth tyne	...	...	3·4
Length of fourth tyne	...	...	13·8
Basal diameter of fourth tyne	...	...	1·1
Length of terminal tyne	9·3	12·4	12·5

Affinities.—The only antler capable of being compared with *C. tetraceros* is that of the Carjacou, or *Cariacus virginianus.* It is, however, much smaller, and possesses a brow-tyne which rises at a distance from the base and at acute angles to the beam, and is different in other respects. From the comparison I should infer that the antler of *Cervus tetraceros* was curved forwards, and that the tynes were erect.

VI. General Conclusions.

We may gather from the study of the fossil Cervidæ the important fact that in the Middle Miocene age the Cervine antler consisted of a simple forked crown only. In the Upper Miocenes it becomes more complex, but is still small and erect, like that of the Roe. In the Pliocene it becomes larger and longer, and altogether more complex and differentiated, some forms, such as the *Cervus dicranios* of Nesti, being the most complicated antlers known either in the living or fossil state. These successive changes are analogous to those which are to be observed in the development of the antlers in the living Deer, which begin with a simple point and increase their number of tynes until their limit be reached. It is obvious from the progressive diminution in size and complexity of the antlers in tracing them back from the Pliocenes into the Upper and Middle Miocenes of Europe, that in the latter period we are approaching the zero of antler development. In the Lower Miocenes I have failed to meet with evidence that the Deer possessed any antlers.

It is further evident from the preceding remarks that the Capreoline type of antler is older than any other.

It is also a point of singular interest to observe that the nearest living analogue of the Miocene Deer is the Muntjak, now found only in the Oriental region of Asia along with the tapir. *Cervus dicranoceros* also coexisted with that animal in the Upper Miocene forests of Germany.

With one exception all the Pliocene Deer which can be brought into relation with living forms are closely allied to the *Axes*, *Rusæ*, or others, which also are dwellers in the Oriental Region. They belong to a fauna now met with only in the forests of India, China, Japan, and the Malay archipelago. The exception is the *Cervus cusanus*, which possessed an antler not very far removed from that of the Roe, an animal now so widely spread over Europe and Northern and Central Asia. I should infer from this that the Oriental Region has offered a secure place of refuge to the Axeidæ, so abundant in the Pliocenes of France and Italy, from those changes in their environment which compelled them to retreat from Europe. The fact of the presence in this quarter of the world of a group of animals now met with only in warm regions, confirms the conclusions as to the warm climate of Pliocene Europe which M. le Vicomte de Saporta has recently arrived at from a study of the vegetation.

Discussion.

Prof. Owen said that he thought we ought to be deeply grateful to the author for the interesting, new, and valuable information his paper had imparted to us. He regarded it as the best and most complete analysis that we possessed of the Cervine fossils, showing, as it did, a close and industrious observation of a vast number of specimens. It was especially valuable for the enlarged and beautiful deductions drawn from individual specimens, and from a comparison of extinct with rare living forms.

Prof. A. Leith Adams agreed with the author in comparing the large horns in one of his diagrams to those of *Rusa equina*. He suggested that the differences in the antlers might be dependent on differences of age, and stated that the antlers described under the name of *Cervus Brownii* really represented the type of *Cervus dama*. One of the small horns resembled youthful horns of *Cervus elaphus*. He had no doubt that the Indian Deer are remnants of Miocene or, it may be, Eocene species.

The President thought the author fully deserved the eulogy passed upon him by Prof. Owen, and remarked that M. Gaudry had just been writing on the same subject. He referred to the appearance of Ruminants with pachydermatoid characters in Miocene times, and inquired whether the antlers of the Miocene Deer were shed or broken off, the horns in *Dicranoceros* being stated by Prof. Gaudry to undergo separation by fracture. He further referred to researches of his own upon the conditions of blood-supply associated with the growth of the caducous horns of existing Deer, and suggested that perhaps the creeping in of a cold climate might induce a failure of nutrition, and cause originally permanent horns to fall off.

The Author defended his position against the suggestions of Prof. Adams, and remarked that the larger and more highly developed forms did not occur along with the simpler Capreoline types of antlers of the Miocene. There could be no question of mistaking his larger antlers for those of Red Deer; their number and constancy of form rendered this impossible. *Cervus Brownii*, he admitted, might be a variety of the living Fallow Deer (*Cervus dama*), but it is certainly not the normal form of the antler of that species. He pointed to a sketch of a specimen from La Grive, which plainly showed that the antlers of *Dicranoceros* were deciduous, and stated that *Cervus Sedgwickii* is probably the same as the *C. dicranios* of Nesti, from the Val d'Arno, in the Florence Museum.

25. *On the* Influence *of the* Advent *of a* higher Form *of* Life *in modifying the* Structure *of an* older *and* lower Form. By Professor Richard Owen, C.B., F.R.S., F.G.S., &c. (Read February 6, 1878.)

In tracing the modifications of structure in a series of animals so similar to one another as to be termed a 'natural group,' one is led to consider the relations to such modifications of concomitant changes in external influences during the geological period of the existence of such group. A difference in the density of the parts of the earth's surface habitually trodden by hoofed quadrupeds has been suggested, for example, as a concomitant, if not causal condition in the transmutation of a five-hoofed perissodactyle (*Coryphodon*, e. g.) to a three-hoofed one (*Palæotherium*, e. g.), thence verging in simplification, through *Hipparion*, to the existing single-hoofed Equines *. Thus it has been observed:—"As the surface of the earth consolidated, the larger and more produced mid hoof of the old three-toed pachyderms took a greater share in sustaining the animal's weight; and more blood being required to meet the greater demand of the more active middle toe, it grew; whilst the side toes, losing their share of nourishment, and becoming more and more withdrawn from use, shrank, and so on, according to the hardening of the ground, until only the hidden rudiments of metapodials remained, and one hoof became maximized for all the work"†.

To this it may be objected that demonstration of such progressive gain of hardness and resistance in parts of the earth's surface, trodden by successive Tertiary forms of hoofed beasts, has not yet been had.

There is, however, another series of conditions which is demonstrated, and which may be legitimately taken into consideration in the relation defined at the outset of the present paper. I refer to the changes in the nature of the prey of certain carnivorous animals.

I assume, at least, a legitimacy of inference from negative evidence, that cold-blooded aquatic animals formed the food of Crocodiles in a much greater proportion in the Mesozoic than in the Neozoic period, and that terrestrial air-breathing animals seldom, if ever, were the prey of the Mesozoic Crocodiles, but were, as now, frequently the food of Neozoic ones.

On this assumption I appreciate, with a satisfaction not felt before, the well-marked distinction in certain parts of the structure of procœlian as compared with amphicœlian Crocodiles. The procœlian

* Intermediate conditions are exemplified in the *Eohippus*, *Orohippus*, *Mesohippus*, of Marsh, from North-American Tertiaries. See his 'Introduction and Succession of Vertebrate Life in America.' 8vo. 1877.

† 'Anatomy of Vertebrates,' vol. iii. pp. 792, 793, and cut 614, "Derivation of Equines" (1868).

ball-and-socket articulation of the trunk-vertebræ better adapts that part of the body to be sustained and moved in air than the amphicœlian articulation which characterizes the vertebral column of the more aquatic, and probably marine, Crocodiles of the Mesozoic periods.

The presence of prey not in existence at those periods, but which, in later Tertiary and modern times, might tempt a Crocodile to rush on shore in pursuit of a mammalian quadruped, is a phenomenon contemporary at least with the acquisition of the procœlian structure in the axial skeleton of such Crocodile.

The extent, the density, the close-fitting articulation of the bony scutal armature of the Mesozoic Crocodilians suggests its use and need in waters tenanted at the same epoch by larger carnivorous marine reptiles,—as, for example, the Ichthyosaurs, Pliosaurs, Polyptychodonts, and Mosasaurs. The Oolitic species of Crocodile ("Crocodile de Caen," Cuv.; *Teleosaurus cadomensis*, Geoff.) is signalized by Cuvier as "l'espèce la mieux cuirassée de tout le genre"*.

But the *Goniopholis* of the Wealden and Purbeck formations surpassed even the *Teleosaurus cadomensis* and its congeners in this part of its organization.

The great quadrangular dorsal scutes of *Goniopholis* are distinguished by the presence of a conical process continued from one of the angles transversely to the long axis of the scute, like the peg or tooth of a tile, which fits into a depression on the under surface of the opposite angle of the adjoining scute, thus serving to bind together the plates of the imbricated bony armour, and repeating a structure which is characteristic of the large bony and enamelled scales of many extinct ganoid fishes. The hexagonal ventral scutes of *Goniopholis* were firmly joined together by broad sutural borders†.

No knight of old was encased in jointed mail of better proof than these Crocodiles of an older world.

But the inimical contemporaries of these Crocodiles passed away. No representative of Mosasaurian, Plesiosaurian, or Ichthyosaurian families lived after the Secondary epoch. Crocodiles alone, of the larger aquatic Saurians, continued on to the present time, more fortunate than their predecessors in respect to possible hostile fellow-denizens of the deep.

Certain it is that the defensive armour of procœlian Crocodiles has degenerated. Bony ventral scutes are exceptional in them‡, and the dorsal ones are fewer, thinner, less closely arranged and less firmly connected with one another. And if this change can be

* 'Ossemens Fossiles,' 4to, tom. v. pt. 2, p. 139; also Eugène E. Deslongchamps, 'Notes Paléontologiques,' 8vo, 1860, pl. xiii.

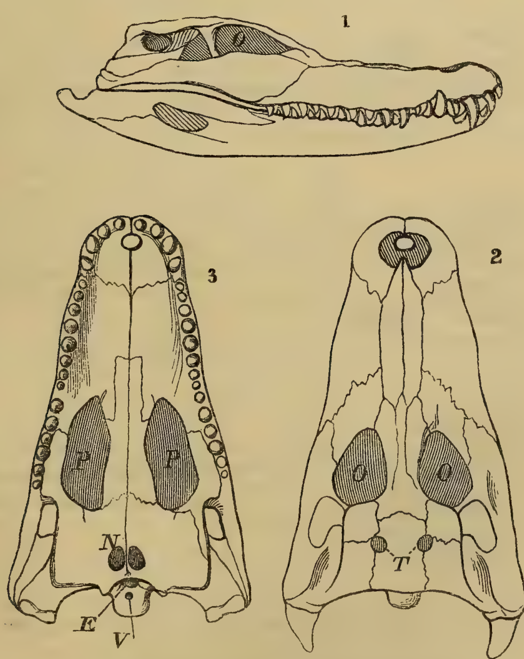
† "Report on British Fossil Reptiles," Reports of British Association, 8vo, 1841, p. 70.

‡ Observed by Natterer in certain South-American Alligators. "Beitrag zur näheren Kenntniss der südamerikanischen Alligatoren," Ann. Wien. Mus. t. ii. (1840) p. 313.

connected with the disappearance of Reptilia, against the attacks of which a better coat of mail may have advantaged the contemporary Mesozoic Crocodilia, it may further be remarked that diminution of weight would favour crocodilian movements in air, and that a loosely jointed armour would less impede the evolutions required to catch a prey on land.

In this relation, also, arising out of the introduction, in Tertiary times, of large many species of warm-blooded mammals frequenting the banks of lakes and rivers tenanted by carnivorous Alligators and Crocodiles, I have been led to ponder upon the well-marked difference in the relative position of the 'palato-nares' (internal or posterior nostrils, figs. 3 & 6 N) which exists between the Secondary and Tertiary Crocodiles.

Figs. 1–3.—*Cranium of* Crocodilus.



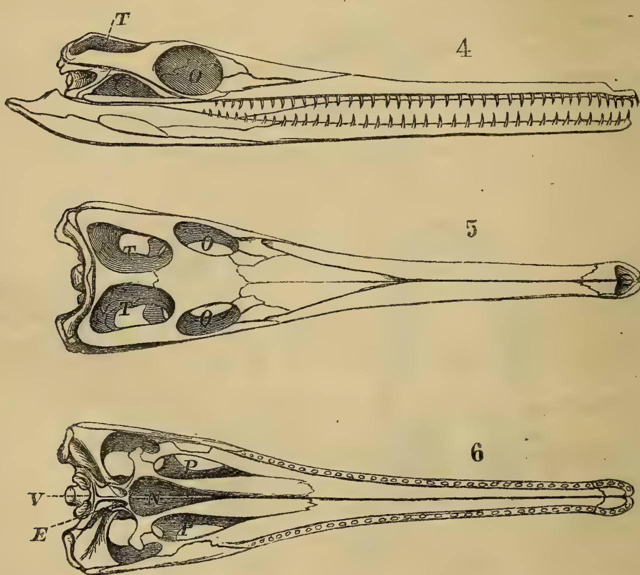
1. Lateral view. 2. From above. 3. From below.

O. Orbits.
T. Temporal apertures.
P. Pterygo-maxillary apertures.
N. Palatal nostril.
V. Venous foramen.
E. Eustachian foramen.

The physiologist discerns in the soft palatal and gular structures, concomitant with the backward position and small size of the 'palato-nares,' in the existing Crocodiles and Alligators of Asia, Africa, and America, the power of holding submerged a powerful mammiferous quadruped, without permitting the streams of water traversing the great cavity of the mouth during the struggle to get access to the posterior nostrils and wind-pipe of the amphibious assailant.

The valvular mechanism applicable to, or, I may say, possible with, the peculiar position of the posterior nostrils of procœlian Crocodiles, opening vertically behind the bony palate, not horizontally upon that plane, could hardly be adjusted to the relatively larger postpalatine apertures, upon a horizontal plane at some distance from the occiput, with the inner nostril opening at a more advanced position in the mouth—an arrangement which characterizes all amphicœlians.

Figs. 4–6.—*Cranium of* Teleosaurus.



4. Lateral view. 5. From above. 6. From below.

Explanation of letters as under figs. 1–3.

No doubt there were sphincteric structures which would exclude water from the glottis in all the aquatic air-breathing reptiles; but the peculiar and well-developed valvular contrivances to that end in existing crocodiles are conditions of the relative size and position of the posterior nostrils in them, and the repetition of that character in the palato-nares of all known Tertiary crocodiles justifies an inference as to the concomitant valvular structures of the soft parts in those extinct procœlian species.

These considerations stimulated or augmented the desire to determine the palatal character of the fossil skulls of those Crocodilia of the newer Mesozoic formations which, in the massive proportions of their jaws, made the nearest approach to the Tertiary and modern kinds. Such demonstration of the structure of the bony palate is accordingly given in the specimens of the Purbeck Crocodiles in the British Museum, which form the subject of my "Monograph on British Fossil Reptilia," in the volume of the Palæontographical Society for 1878.

Although the jaws of *Goniopholis crassidens* and *Goniopholis simus* have proportions adapted to grapple with large and active mammals, the evidence of any such warm-blooded air-breathers coexistent with those Crocodilia is not yet acquired. And the probability of such coexistence is, in my opinion, very small, from the circumstance of the palato-nares being relatively larger and more advanced than in the Crocodiles contemporary with such mammals. The palato-nares in *Goniopholis* open likewise upon a horizontal plane, look directly downward, not obliquely forward, and, moreover, have a different anatomical conformation. Instead of being formed or bounded by the pterygoids exclusively, as in Tertiary Crocodiles, the palatine bones enter into the formation of the anterior third of the circumference of the palato-nares.

With this anatomical character, which I am disposed to associate with a fish diet, are combined, in both *Goniopholis* and *Petrosuchus*, upper temporal apertures larger than the orbits and amphicœlian or amphiplatyan vertebræ.

Now all known Tertiary and existing Crocodilia combine with small, posterior, pterygoid palato-nares, upper temporal apertures (fig. 2, T) less than the orbits (*ibid.* O); and in some broad-faced kinds the upper temporal apertures are almost obliterated by the progressive increase of the osseous roof of the temporal vacuities. These vacuities, in the recent reptile, are occupied by the temporal muscles, and the power of these biting and holding muscles is in the ratio of the extent of their bony origins.

In the amphicœlian fish-eating Crocodilia, the upper temporal apertures (fig. 5, T) are larger, and usually much larger, than the orbits (O); and they are, for the most part, associated with slender jaws and with numerous, small, uniformly sized teeth (fig. 4).

With the palatine modifications which relate to the drowning of air-breathing prey, and with the cranial developments which relate to the grip of such prey, we find, as a rule, in procœlian Crocodiles, concomitant modifications in the breadth (fig. 2) and strength of the jaws, in productions of the alveolar borders, and in the size of the teeth (fig. 1). There is also inequality of size, favouring holdfast, as in mammalian Carnivora; and certain teeth of the dental series have accordingly received the name of canines in the Crocodiles with such analogous dentition.

In this comparison and its applications I propose at present to conclude with reference to a limb-character distinguishing the *Amphicœlia* from the *Procœlia.*

In all the Mesozoic Crocodilia of which the skeleton has been sufficiently restored, the fore limbs are shorter in proportion to the hind limbs than they are in the similarly restored Neozoic species *. The difference relates to the more strictly or uniformly aquatic life of the Teleosauroids. This I deduced from the fact that when a Nilotic Crocodile swiftly swims to catch a prey or escape a danger the fore limbs are closely applied to the trunk. The same motionless and unobstructive disposition of the fore limbs has been observed in the marine lizards of the genus *Amblyrhynchus* †.

But the resistance to rapid swimming from fore limbs when so disposed will be the less as the size of such limbs may be diminished.

Thus the Teleosauroids, in their rush after fishes or retreat from Ichthyosaurs, would be favoured by the character of the fore limbs above adduced.

On the other hand their progress on dry land would be more difficult, unless, like the Dinosaurs with similarly stunted fore limbs, they were able, as has been surmised, to run upright on their hind legs, as shown in a photograph of the "Restorations of North-American Dinosaurs and Pythonomorphs" exhibited in the "Central Park of New York." I am, however, disposed to see in the Teleosaurian proportions of the fore limbs in the long-natatory-tailed Iguanodon and Hadrosaur a condition facilitating their locomotion in water.

But, returning to my immediate argument. To what condition, it may be asked, do the augmented size and strength of the fore limbs in Neozoic Crocodiles relate?

The advent in Tertiary time of large mammalian quadrupeds browsing or prowling along the shores of estuaries and banks of rivers haunted by such Crocodiles might, and does, tempt them to make a rush on the dry land to seize such passing prey. In these rushes the fore limbs come into strenuous play as terrestrial locomotive organs.

A Lamarckian might say that the temptation to such locomotion, by the repeated increased exertion and exercise of the fore limbs, would lead in the course of generations to their augmentation of size; and he would set it down as one of the factors in the transmutation of a Teleosaur into an Alligator. His opponent might call for the evidences of the transitional forms.

It is true that, in regard to the general shape of the head, some of the later Mesozoic Crocodilia approach, exceptionally, the more robust proportions which prevail, as a rule, in Neozoic Crocodilia, and that among these latter there are species which exceptionally show the more slender proportions which prevail, as a rule, in the Mesozoic

* 'History of British Fossil Reptiles,' *Crocodilia,* pl. 1, 4to, 1850 (skeletons of *Teleosaurus* and *Gavialis*).

† Darwin, 'Voyage of the 'Beagle;' 'Journal of Researches' &c., 12mo, 1845, p. 386.

Crocodilia. But in the vertebral, the dermoskeletal, and the palato-narial characters there is no known exception to the modifications which severally characterize the amphicœlian and procœlian Crocodiles.

We find, as the Secondary approach the Tertiary periods, that the *Goniopholis*, for example, of the Purbeck and Wealden series shows a nearer approach, in the shortness and breadth of the facial part of the skull, to the majority of the Tertiary and existing Crocodiles than the Oolitic and Triassic amphicœlians exhibit; while the long and narrow jaws, with the series of small, sharp, uniformly-sized teeth, in a straight row, common to Teleo- and Steneosaurians are now exceptionally manifested by the single genus *Gavialis*, with a very limited geographical range. Such forms and proportions of the jaws and teeth, with some minor dermal modifications affecting scutes and foot-webs, justify the generic status of the Indian Gharrials.

The claims of the American Alligators to generic honour rest on feebler foundations; and in regard to the procœlian Crocodiles of the present day, the work of what our German friends have termed the "Gattungsmacherei," has been most productive. *Tomistoma*, *Oopholis*, *Halcrosia*, *Palæosuchus*, *Rhynchosuchus*, *Rhamphostoma*, *Mecistops*, *Bombifrons*, *Palinia*, *Molinia*, *Caiman*, and *Jacare* hardly exhaust the multitude of names generic with which herpetology has been encumbered. What is of main importance to know is, that all the Crocodiles bearing the above names have the following characters in common :—the upper temporal apertures smaller than the orbits ; the palato-nares small, formed by the pterygoids exclusively, placed far back and on a slope towards the occiput; the vertebræ procœlian.

These Crocodiles vary in respect to the proportions of length to breadth of skull, in the relative length of the nasal bones, in the proportions and course of sutures of the premaxillaries, in the degree of difference of the size of the teeth in the same species, and in the relation of some of the larger lower teeth to the upper jaw when the mouth is shut, also in the number and arrangement of the dermal scutes and in the extent of the toe-webs. And such characters are available, by their observed constancy, in the discrimination of the existing species of Crocodilia.

The connoting of the more essential characters common to the procœlian series, and of those which in like manner were common to the amphicœlian series, has led to the consideration of the concomitant and seemingly influential conditions of such respective organic characters, more especially of the relation of the procœlian modifications to the coming in of the mammalian class, and perhaps to the going out of certain members of the reptilian class : and such considerations are now submitted to the judgment of the Geological Society.

Discussion.

Professor Seeley gathered that the chief object of Prof. Owen's paper was to show that the modern Crocodiles have been evolved from those of the Secondary rocks, and in consequence of the altered conditions of their struggle for existence which resulted from the development of mammalian life in Tertiary as compared with earlier ages. While admitting the evolution, he thought it had no necessary dependence upon the incoming of mammalian prey. Thus the removal backward of the palato-nares in the modern Crocodiles was a condition that would be gradually and inevitably developed, even if mammals had not existed. In the living Crocodile these nares are surrounded by the pterygoid bones, and to the dorsal surface of those bones enormous muscles are attached, which form great hemispherical masses on each side of the head, and are attached to the inner side of the lower jaw. But in the Secondary Crocodiles this pterygoid region of the palate makes a nearer approach to the condition of the bones and palato-nares in certain lizards. And since in the lizards the internal pterygoid muscle has no such development, owing to the larger size of the temporal muscle, he considered that the gradual increase in size of the pterygoid muscles, consequent on the lateral action of the jaws in tearing food, was the cause of the osseous differences of the palate in this region in the two types, because the tension of the muscles acting on the pterygoid bones at their suture with the palatines would cause those bones to elongate, and as the muscles grew more powerful the palato-nares would thus be carried further and further backward with the bones which embrace them; and similarly, by lateral tension, the pterygoid bones would grow in the line of the median suture and so widen, while they reduced the size of the aperture of the palato-nares. This physiological explanation seemed to be independent of the condition of prey being mammalian.

Dr. Meryon was sorry that the author had not gone to the full length in regard to evolution, and, referring to the backward position of the palato-nares, said that this was a provision adapted to their holding their prey under water to drown it. He also referred at some length to the influence of the nervous system in inducing changes.

Mr. Hulke observed that with respect to Prof. Owen's idea that warm-blooded animals were not preyed on by the Mesosuchian Crocodiles, it could not be doubted that such did actually exist contemporaneously with them, and that they might become an easy prey when fording rivers or lakes, as at the present time. He thought that the inference drawn from the strong scutal armour of the Mesosuchia, that these lived in presence of stronger and larger animals, and so stronger armour was necessary for their defence, was not justified by the facts of to-day. The Jacquari of Tropical America, as an example, is similarly armoured, yet has no larger and stronger adversaries. In referring to the suggestion that the backward position of the palato-nares was an adaptation to exclude the entrance of water into them whilst struggling with a drowning prey, he thought this exclusion was brought about mainly by the closure of the exterior nostrils, since if these were closed, the nasal passage being filled with air and not a vacuum, water could not enter the posterior nares by the mouth. It was, however, the exclusion of water from the glottis and not from the posterior nares which is important. The narial passages and trachea do not form a continuous, but an interrupted tube, without the admirable contrivance which Cetaceans have of a conical larynx, which can be raised and plugged into the palato-nares; for the upper opening in Crocodiles is a simple slit, not particularly prominent, and not capable of such exact adjustment to the palato-nares as in Whales.

Mr. Hicks asked if, with the cessation of the existing circumstances, the acquired structural modifications would cease and the Crocodile go back to its primitive form.

Sir Philip Grey-Egerton observed that in the beginning of the paper the author noticed the modifications of structure of mammals adapted to the surface of the earth, the splay-footed ones moving better over the soft surface; but it must not be overlooked that with these coexisted narrow-footed forms. He thought that the author should have shown that the splay-footed ones alone existed then.

Prof. Owen, in reply to Dr. Meryon, said that he was gratified to find that his paper had called forth the remarks to which he had listened with pleasure from his old and esteemed friend. It would be seen, however, that his paper was teleological rather than evolutionist, indicative of how the structures characterizing the Neozoic Crocodilia would operate in giving them advantage in the capture of terrestrial prey. No doubt a reference had been made to the Lamarckian view of the conditions under which such modifications of structure might be acquired, and the requirements, by an objector, of the intermediate stages of the change from the amphicœlian to procœlian types was referred to. Instances of that character were few, but might be cited. The Mesozoic *Goniopholis*, *e. g.*, with broad thick jaws, wavy alveolar tract, and large and unequal teeth, combined these Neozoic characters with the Mesozoic large, horizontal, advanced palato-nares. The existing Gavial retains the long narrow jaws, straight alveolar tract, numerous small and similar-sized teeth, with the small, subvertical, posteriorly placed palato-nares characteristic of Neozoic Crocodiles. Considering the enormous lapse of time between the Wealden and Eocene periods, it may reasonably be expected that many more of these "missing links" will be found; and one object in our allusion to them in this paper, honoured by Dr. Meryon's remarks, was the additional stimulus it held out to palæontologists and intelligent collectors of fossils to researches which might be rewarded by such discoveries.

With regard to that part of Mr. Hulke's objection bearing on the scutal characters of Mesozoic and Neozoic Crocodiles, it is true that, as Natterer has pointed out, the ventral as well as the dorsal scutes of the Jacquari are ossified; but those scutes are less firmly connected together; they are united neither by the peg-and-groove mechanism, nor by thick sutural margins; and the advantages of diminished weight and increased freedom of inflection of the trunk are still possessed unexceptionally by the procœlian Crocodiles.

Prof. Owen remarked, in reply to Sir Philip Grey-Egerton, that the objection that other quadrupeds besides hoofed ones trod the Tertiary earth no doubt would apply to the quotation introductory to his paper, but that was made merely to exemplify the meaning of the title. "A change of characters concomitant with change of density in the earth's surface" was analogous to "a change of characters concomitant with the introduction of new forms on that surface." But the difference between the quotation and the subject-matter of the paper was that the changes of density were hypothetical and unproven, whereas the coming-in of large mammalian quadrupeds at the Tertiary period was an accepted fact.

26. Note *on certain* Modes *of* Occurrence *of* Gold *in* Australia. By Richard Daintree, Esq., F.G.S. (Read February 20, 1878.)

[Plates XVII., XVIII.]

In a paper read before the Geological Society in April 1872, on "The Geology of Queensland," it was pointed out that a large area of Devonian rocks existed in that colony, and that numbers of gold-fields had been opened on such areas.

Attention was, however, drawn to the fact that the auriferous tracts were entirely confined to such of those Devonian districts as were found to be penetrated by certain plutonic rocks, principally pyritous diorites.

In these diorites, and at and near their intersection with the Devonian strata, auriferous quartz, calc-spar, and pyritous reefs had been examined, and were proved to be rich in gold, whilst the extension of such veins at any considerable distance from the intrusive rocks was found to be barren.

Instances were also adduced to show that the pyrites sporadically distributed through the diorites were occasionally decidedly auriferous, and by their decomposition and degradation had yielded alluvial drifts containing gold in paying quantities to work.

Since this was written I learn from Mr. C. Wilkinson, the Government Geologist of New South Wales, that the same facts hold good for those New-South-Wales gold-fields which lie in Devonian or Upper Silurian areas; and Mr. G. Ulrich, the talented Curator of the Technological Museum in Melbourne, in his Catalogue of the rocks in that Museum, gives details which prove beyond doubt that the Upper Silurians of Victoria owe their auriferous character to the same cause.

He describes the diorites as occurring in Victoria, mostly as dykes varying in thickness from a few to several hundred feet, traversing Upper Silurian rocks and presenting nearly all the ordinary varieties of texture and mineral composition. They are nearly always impregnated with auriferous pyrites, and traversed by, or associated on one or both walls with, auriferous quartz veins; and by far the greater quantity of the quartz-gold furnished by the gold-fields occupied by Upper Silurian rocks is derived from such diorite dykes. In support of these statements, Mr. Ulrich mentions several important workings connected with these dykes, and especially notices the dyke of Cohen's Reef (which, he says, is perhaps the richest one in the colony, and some specimens from which represent the variety "diorite aphanite"), and the dyke of the Albion Mining Company, at Crossover Creek in North Gippsland, which is interesting on account of its highly micaceous character, and its influence upon the gold-bearing character of the reefs which traverse it at right angles to its strike, and which, poor in the

Upper Silurian strata on each side of it, become richly auriferous throughout the width of the dyke (about 90 feet).

The practical value of these facts is great, as it narrows the search of the prospector for gold in the Devonian and Upper Silurian areas of the Australian Alps to the portions penetrated by certain intrusive plutonic rocks, or at all events primarily and especially to such areas. I have therefore been induced to lay before the Society some further notes on the subject.

With regard to the practical value of the rock containing the sporadically diffused pyrites, I previously expressed an opinion that "the noble metal would not often be found in sufficient concentration in this form to become a source of supply in any material degree."

I instanced the case of the "Tunnel" and "Greens" so-called reefs, at the Upper Cape, Queensland (which were simply decomposed pyritous trachytes or felsites), as the only evidence we then had of such a trial being made; and in neither case had the result induced the owners to continue their work beyond a few trial crushings, which yielded about 12 dwts. per ton.

Since this was written, Mr. Ulrich has described a parallel case in the so-called Peninsular Reef at Portobello *.

According to Mr. Ulrich this so-called reef has been opened in four places, lying nearly in a line down the steep slope of a mountain there, composed of greyish-white trachyte. The highest opening is a short prospecting drive in which quartz of a rather concretionary character was found in an irregular bunch, amounting in quantity to about one ton; in this no gold was seen. The second opening, about 100 feet lower down, is a shallow excavation in trachyte, which is here full of irregular siliceous segregations like quartzite, containing an abundance of very fine grains of pyrites. A trial crushing of 2 cwt. yielded 18 grains, and one of half a ton $\frac{1}{2}$ ounce of gold; and the prospectors stated "that they could wash a pretty fair prospect of gold out of every tin dish full of the stuff excavated." The third opening, about 60 feet lower down, is a small open cutting in a very close-grained white trachyte, a trial crushing of one ton of which yielded 3 dwts. of gold. The fourth opening, at the foot of the mountain, is a shaft 40 feet deep, with a small drive at the bottom. The first 25 feet passed through loose ground, and the remainder through a decomposed cap into a hard coarsely crystalline rock, composed of hornblende, triclinic felspar and some quartz, and more or less densely charged with fine grains of pyrites. Two trial crushings of the hard rock, of one ton and half a ton, yielded respectively 8 dwts. and 11 dwts. of gold, whilst a ton of the softer decomposed rock, which might have been expected to be richer, only gave 6 dwts. As there is no evidence that the above-mentioned openings have been made in the line of a peculiarly auriferous zone or streak, and it is very improbable that the auriferous portions of the rock were hit upon by accident, Mr.

* 'Geology of Otago,' Hutton and Ulrich, p. 165.

Ulrich thinks it likely that gold is generally disseminated more or less abundantly through these peculiar varieties of rock as far as they extend.

The case of the Peninsular Reef at Portobello does not offer any better prospect to the miner than the "Greens" and "Tunnel" so-called reefs; so that all present evidence goes to show that so diffused auriferous pyrites are not of *direct* practical value.

Where, however, mechanical concentration has taken place in the shape of alluvial deposits from such pyritous rocks, they have been found to pay the miner—*e. g.* the alluvial deposits of Paddy and Sharpers Gullies at the Lower Cape, Queensland, the Gooroomgam diggings, and the pyritous granites of Bowenfels and Hartley, New South Wales.

The question when the auriferous pyrites were deposited in these rocks is an interesting one, which requires extended and careful microscopic investigation to solve. My own opinion is that most of such pyrites are contemporaneous with the consolidation of the rocks in which they occur, although some may owe their origin to the passage of solutions through the rock at a subsequent period. I have examined a large number of sections of pyritous diorites, felsites, and granites of the auriferous series from Victoria, New South Wales, and Queensland, and only in a few instances find portions of the matrix rock imbedded in the pyritous crystals, a copy of a photograph of one of which is given in Pl. XVII. fig. 2.

Here both felspar crystals and portions of felspar and altered hornblende similar to the other portions of the rock are enclosed in the pyrites, and felspar crystals also run into the pyrites, as if the consolidation had been nearly contemporaneous, and not as if the pyrites had filled decomposed portions of the rock, as calc-spar is seen to do in some places; but this never contains enclosures of felspar or any other constituent of the rock substance.

Professor Judd, in treating of the similar occurrence of gold in the Schemnitz districts of Hungary*, says, "In every instance we find proofs that the more deeply seated masses of andesitic lava have, in consolidating, assumed a highly porphyritic or granitiform structure, and that the action upon these of acid gases and vapours has resulted in the decomposition of the mass, with the diffusion of valuable metallic ores throughout the substance of the rock and their accumulation in considerable quantities wherever a suitable fissure occurred in it."

To apply this form of reasoning to such cases in Australia it would be necessary to show that the portions of the rock lying below or without the line of decomposition ceased to contain auriferous pyrites, which is by no means the case; the zone of decomposition is generally at or near the water-level of the district in rocks difficult to decompose; in softer rocks it may go much below this zone; but when the undecomposed rock is reached, the sporadically developed pyrites still continue a constituent, and indeed

* Quart. Journ. Geol. Soc. August 1876, p. 323.

appear in larger proportion, as they are then more readily distinguishable than in the decomposed rock, where they are usually represented by iron-oxide or empty cubical cavities *.

Below the zone of decomposition, however, we generally lose a class of auriferous veins which has proved very misleading to the miner, though usually very rich in gold. These usually follow the line of jointing in the rock, and are, in my opinion, simply due to the decomposition of the auriferous pyrites and of the country rock and the redeposit of such of the decomposed material as passed into chemical solution in local fissures.

An instance of this is well shown in enlarged microscopic section, fig. 4. This is enlarged 9 diameters, and is from the Black Snake district in Queensland, where such veins are numerous. It will be seen that the vein (the first constituents of which seem to have consisted almost entirely of quartz) has been opened, apparently by the elastic force of crystallizing minerals, both from the sides and the centre, the crystallizing mineral holding within it fragments of detached quartz.

Looking at this vein, however, teaches distrust of the reasoning that pyrites even containing included detached portions or crystalline constituents of the bounding rock would be formed contemporaneously with such rock.

As the pyritic constituent in the intrusive rocks of the Black Snake mining-district is chiefly copper pyrites, the auriferous veins sometimes contain as much as 20 per cent. of copper; and black patches of the vein shown in fig. 4 consist principally of oxide of copper and metallic copper with some oxide of iron; the gold is rarely visible to the naked eye.

Figure 3, of a pyritous felsite from the Alexandra diggings in Victoria, will give a good idea of the probable commencement of such a vein as is shown in fig. 4 in a more advanced stage. It is enlarged 60 diameters.

It is probable that to this mode of formation are to be attributed all such horizontal veins as those depicted in Mr. Selwyn's Exhibition Essay, 1866, of Shakespeare's Reef, Gaffneys Creeks.

Besides these veins, however, there are associated with the intrusive auriferous plutonic rocks others of far more practical importance, as many are likely to be persistent in depth and generally of greater width, namely those formed by hydrothermal action, which preceded and was contemporaneous with the intrusion of the rock, and continued in some instances long after the intrusive rock itself had cooled down.

These fill cracks formed by the explosive power of the gases, into which, in some cases, the fused material did not penetrate, as well

* Near Baynton's Station, in Victoria, a dense basalt is impregnated with magnetic pyrites; and all the copper-ore of the Okatiep and other mines of Namaqualand is obtained from highly felspathic dykes which show no signs of decomposition at a short distance from the surface, the ores (pyrites and peacock ore) being distributed through the rock partly in small grains, some of them not larger than a pin's point, and partly in masses which may attain a weight of several cwt.

as the main cracks of cooling of the igneous rock, many of which were probably opened again and again, forming chimneys for the escape of gaseous emanations from below.

That the gold in a reef may have been introduced at different periods, we have constant evidence in practical mining all over Australia, where the precious metal is usually found in some particular part of the larger veins, either near the hanging or foot wall, in the centre, or in "shoots," dipping at an angle across the strike of the lodes, the remainder of the reef being entirely or comparatively barren. In small veins this is also often a very marked feature.

Figure 1, which is enlarged two and a half diameters, from a section of an auriferous quartz reef, shows clearly that the first deposit from either wall was barren quartz of a crystalline character—that then a break took place in the centre, which was accompanied or followed by a very rich deposit of gold, and this gold of the filiform and semicrystalline appearance so characteristic of that associated with intrusive rocks, and which is called by the diggers "spider-leg" gold.

With regard to the age of the gold in Australia, I think all the evidence goes to show that the auriferous veins were chiefly formed during the earliest era of great volcanic agitation of which the stratified rocks give evidence in their interstratified ashes and lavas, as well as the volcanic cores or dykes; and this period was assuredly the Devonian *.

In my last report as Geologist to the Queensland Government, I pointed out that the miners of one of the diggings near Peak Downs were finding waterworn gold in a Carboniferous conglomerate containing *Glossopteris*, making a "bottom" of an underlying conformable shale abounding in *Glossopteris*. Mr. Wilkinson, the Government Geologist of New South Wales, has lately recorded a parallel fact as occurring at Gulgong, thus showing that some auriferous quartz veins, at least, were formed prior to the Carboniferous period in Australia.

The only reason, in my opinion that waterworn gold has not been more frequently found in similar conditions is, that marine and lacustrine deposits, such as the Carboniferous and all the Mesozoic and older Cainozoic strata of the continent, are chiefly built up of sediments not derived from the rocks on which they rest. Only beaches or locally filled fjords of Carboniferous or Mesozoic sea-coast, where auriferous reefs cropped out, and had a chance of extensive abrasion, would be likely to contain drifted gold.

Between the Palæozoic and Cainozoic periods in Australia there appears to have been an almost entire cessation of the volcanic forces.

* In my previous paper on Queensland geology, the metamorphic series is provisionally grouped below the Devonian; but I much doubt whether it is not in most cases, if not in all, simply Devonian strata altered by contact of large masses of intrusive rocks, principally granite, as it is nowhere found at any considerable distance from such masses. No Lower-Silurian fossils have yet been found in any part of the colony.

During the so-called Miocene Tertiary epoch, however, intense activity was again manifested, to be again renewed, after a period of quiescence, during the so-called Pliocene Tertiary.

Mr. Selwyn was of opinion that the gold was introduced into the quartz veins of Victoria at some period apparently between these two epochs; for, arguing on certain data developed in the Moorabool valley, he says: "These particular drifts are clearly antecedent in date to the upper and middle marine Miocene beds under which they have now been traced. They do not contain gold in *paying quantity*, the reason being that they are derived from the abrasion of quartz veins that themselves contained little or no gold, and that they were probably formed by forces in operation as long prior to those which produced the gold-bearing veins, as the denudations producing the Miocene gravels were prior to the Pliocene productive ones."

Mr. Selwyn may be right with reference to the fresh introduction of gold into the quartz veins during the periods he mentions; but the data on which he bases his evidence are hardly, I think, sufficient to support the inference.

These so-called "non-auriferous lower drifts of Victoria," crop out on the beach in Bass Straits, about a mile west of the Bird Rock, south of Geelong, in exactly the same geological position as those referred to by Mr. Selwyn on the Moorabool river, the cliff sections showing the Lower Miocene clays and marls resting immediately on them, full of marine fossils.

They differ in one respect only from their representatives in the Moorabool valley, that here they rest on the Mesozoic Carbonaceous series of Victoria, which is chiefly composed of grey sandstones and shales, whilst in the Moorabool valley they rest on Silurian slates.

They represent, however, near Bird Rock, no more the degradation of the strata on which they rest than do those of the Moorabool valley; they form part of a great marine drift, whose material was, in my opinion, derived from the south; and the further north we go towards the higher levels, the more the whole middle Cainozoic system thins out, until it ceases altogether, to be again met with in the Murray basin at about a corresponding point above sea-level.

What would seem to be the real reason why the lower and middle Cainozoic rocks of Victoria do not contain drift gold in paying quantity, and the upper Cainozoic do, is that the one series is essentially a marine drift; the other is fluviatile, or, where auriferous, is essentially so, consisting of the débris of rocks disintegrated by atmospheric influence—arranged, sorted, and concentrated in continuous water-sheds by fluvial action, the heaviest particles, such as the gold, being in no case removed far from their original matrix.

Undoubtedly auriferous quartz veins have been formed during the Cainozoic period both in Hungary and at the Thames Diggings in New Zealand; but the veins there are, in both cases, in Plutonic rock, or at or near the intersection of the Cainozoic strata with Plutonic rock.

Now in Australia at present no auriferous vein of any kind has *been found in any sedimentary rock of the Mesozoic or Cainozoic groups or in any Plutonic rock erupted through such strata.*

There is therefore no direct evidence to show that in Australia any auriferous vein has been formed later than Palæozoic times; or if it has, it has never had the pluck to show its head above Palæozoic strata. Moreover the dykes which traverse the Mesozoic and Cainozoic rocks in Victoria do not resemble in any respect the diorite and other auriferous dykes of Gippsland which traverse the upper Palæozoic rocks; but all are augitic in character, similar to the Cainozoic lava-sheets with which they are associated.

It may be, however, that gaseous emanations, highly auriferous, attended with sufficient force to open old lines of reefs, did take place at the close of the Miocene and preceding the Pliocene volcanic activity, unattended with the intrusion of volcanic material; but these would more likely form the rich "shoots" in the lodes, so constantly met with in Victorian mines, and not have formed enormous reefs, such as those of Clunes and the Black Hill at Ballarat.

Further careful observation is required to clear up this subject; but the result of such inquiry would probably confirm the assertion that the majority of auriferous veins in Australia were formed during the Upper-Palæozoic period, and were afterwards enriched during both the great Cainozoic volcanic epochs. The Mesozoic seems to have been a period of almost entire volcanic quiescence.

In conclusion, it would seem desirable to note the different modes of occurrence of gold in Eastern Australia, for the information of explorers in other countries:—

1. In *pyritous diorites*, e. g. Gooroomjam Diggings, Queensland; alluvial drifts from these contain gold in paying quantity.

2. In *pyritous felsite*, e. g. Paddy's and Sharper's Gullies, Cape Diggings, Queensland; the alluvial drifts from these very rich.

3. In *pyritous granite*, e. g. the granite of Bowenfels and Hartley, New South Wales.

4. In alluvial drifts derived from the degradation of serpentine, e. g. Canoona Diggings, Queensland. In neither of these cases has the rock been found to pay for crushing.

5. In irregular strings and veins of quartz and other matrix, evidently the result of the decomposition of the auriferous pyrites of Nos. 1, 2, 3, and their redeposit from chemical solution.

6. In pyritous quartz and calcspar veins in the rocks of Nos. 1, 2, 3, 4 (better defined, more permanent, and wider than those of No. 5), whose matrix and mineralization has been derived partly from the bounding rocks, but mainly from the hydrothermal action from below, and which have been repeatedly opened for the introduction of fresh material. E. g. Gympie, Upper Cape, Etheridge, and Mount-Wheeler Diggings, Queensland, the Queensland and New-South-Wales diggings generally, and the Gippsland district of Victoria.

7. In quartz and other veins in Devonian and Upper Silurian strata in immediate proximity to rocks of Nos. 1, 2, 3 types, e. g. Queensland and New-South-Wales diggings generally, and larger

districts in Victoria. It is probable that in depth all such veins will be found connected with the neighbouring intrusive rocks, as at the Upper Cape, Mount Davenport, and Specimen Gully at the Cape-River diggings, Queensland.

8. In quartz veins traversing metamorphic rocks of undetermined ages, in some cases associated with dykes of plutonic rock, in others apparently free from such influence, e. g. the Cape and Peak Downs diggings, Queensland.

9. In quartz veins traversing Lower Silurian rocks without any apparent connexion with plutonic dykes.

These cases are only met with in Victoria, to which colony, I believe, the Lower Silurian rocks are confined. These veins are generally thicker than those associated with "dykes," but do not afford one quarter the yield of gold per ton (the gold from this class of vein also contains, as a rule, far less silver than those connected with "dykes"), are not nearly so pyritous, and rarely have an admixture of calcspar "gangue."

EXPLANATION OF THE PLATES.

Plate XVII.

Fig. 1. Section of an auriferous quartz-vein, enlarged $2\frac{1}{2}$ diameters. The gold is represented in black; and it will be observed that the coarsely crystalline quartz of the outer walls is entirely free from the precious metal.

Fig. 2. Section of a highly pyritous auriferous diorite. The black shows the pyrites in which fragments of the constituents of the diorite are enclosed. This section is enlarged about 60 diameters.

Plate XVIII.

Fig. 3. Section of a highly pyritous auriferous felsite from Victoria. It is enlarged about 60 diameters. The quartz vein, which is a mere streak in the original section from which it was enlarged, is evidently contemporaneous with the rock; but the pyrites in it is much more decomposed, and the commencement of a secondary vein is evidently being set up.

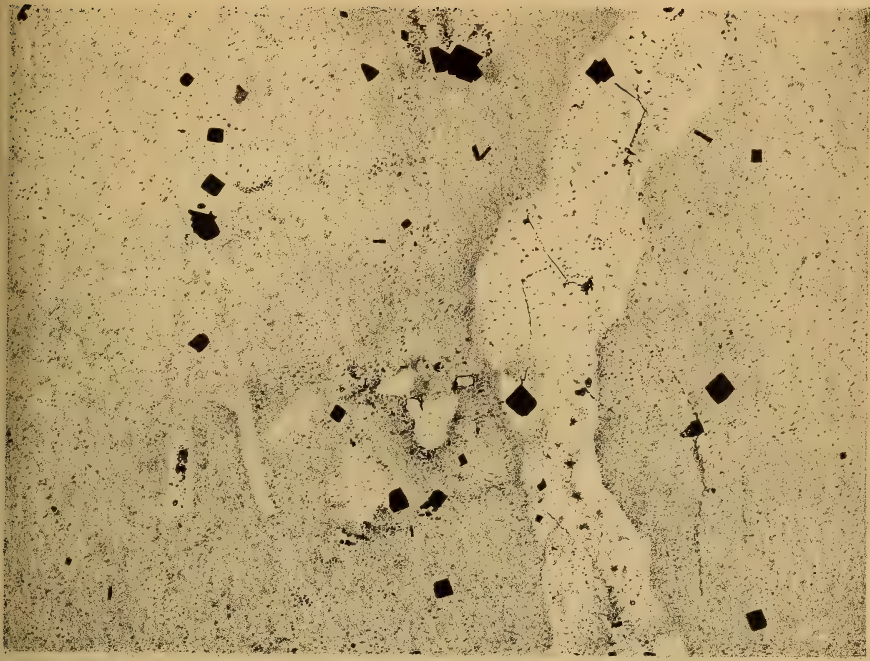
Fig. 4. Section, enlarged about 9 diameters, of an auriferous quartz-vein in a porphyrite; the materials of the vein having evidently been formed from the decomposition of the ingredients of the bounding rock, which is highly charged with decomposed copper and iron pyrites. The black in the vein is chiefly iron- and copper-ore, though metallic gold is visible in minute specks.

1.

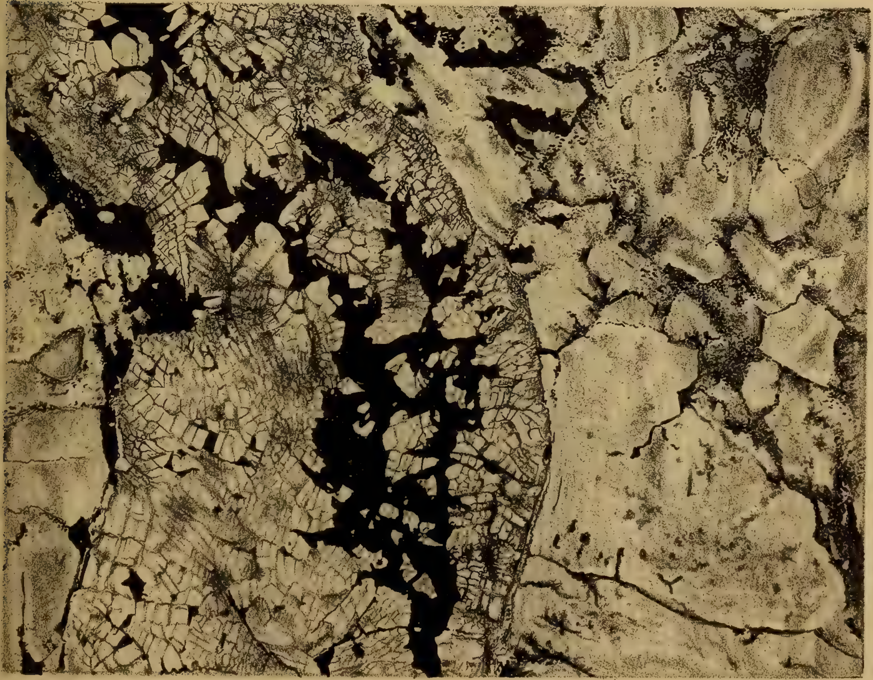
2.

Mintern Bros imp.

AUSTRALIAN AURIFEROUS ROCKS.



3.



4.

Mintern Bros imp.

AUSTRALIAN AURIFEROUS ROCKS.

27. Description *of a* New Fish *from the* Lower Chalk *of* Dover. By E. T. Newton, Esq., F.G.S., of H.M. Geological Survey. (Read March 20, 1878.)

[Plate XIX.]

In a former communication to this Society* I described certain specimens of fish-remains from the Cretaceous rocks of Britain which I believe to be the English representatives of *Portheus* and *Ichthyodectes*. In the present paper I have described another Cretaceous fish, belonging, as I think, to *Daptinus*, a third American genus not hitherto recognized in this country.

The specimen, which is imbedded in a block of Grey Chalk, was obtained from Dover by Mr. J. S. Gardner, and is now in the British Museum (no. 47250). It has been admirably developed under the careful superintendence of my esteemed friend Mr. W. Davies, to whom I am much indebted, as also to Dr. H. Woodward, for the facilities afforded me for the examination of this fossil. It consists of a skull with the facial and opercular bones of the left side almost perfect, and retaining very nearly their natural relations to each other. The surfaces of the bones are mostly abraded; but where they remain apparently intact, they exhibit no kind of ornamentation, except the radiating lines indicative of the direction of growth, which are commonly to be met with on teleostean fish-bones. In a side view (fig. 1) four vertebræ are to be seen; but probably two others intervene between the anterior of these and the skull, and most likely two more are overlain by the bone marked *pt.tem.*

The teeth have long, hollow roots, sunk in deep sockets, and were replaced vertically—characters which are displayed by a fortuitous fracture of the maxillary bone. The præmaxilla and maxilla are firmly articulated with each other, the former being a very short, but deep, bone. The symphysis of the lower jaw is deep. In all these particulars this specimen closely resembles *Portheus* and *Ichthyodectes*; and its close affinity to them is further shown by the form of the vertebræ. Bearing these characters in mind, and noticing also the regularity of the teeth, it seemed at first that this specimen must belong to the genus *Ichthyodectes*; but a comparison with the species of that genus showed that, in certain particulars in which it differed from them, it agreed with Cope's description of *Daptinus*†. The chief difference given by Prof. Cope as existing between *Ichthyodectes* and *Daptinus* is that the latter has the crowns of the teeth much compressed and with knife-like edges. Now our specimen agrees

* Quart. Journ. Geol. Soc. vol. xxxiii. p. 505.

† United-States Geol. Surv. Terr. vol. ii. Cret. Vertebrata, p. 213.

with this definition of the latter genus; but then, although the crowns of the teeth are compressed and the edges sharp and knife-like, yet they are not so much flattened as they appear to be in *Daptinus*; and, moreover, the teeth in some species of *Ichthyodectes* seem to make an approach towards this form. So far then as the teeth are concerned, our specimen might be taken as an intermediate form, and could be placed with equal propriety in either of these two genera. With regard to the form of the mandible this specimen differs from all the known species of *Portheus* and *Ichthyodectes* in that it is longer in proportion to its depth, and has a shallower symphysis. There is no groove near the lower margin as in some species of *Portheus* and *Ichthyodectes.* The inner side of the alveolar margin cannot be seen; and therefore it is doubtful whether or not there are foramina, such as are said to characterize the type specimens of *Saurodon* and *Saurocephalus.* Another peculiarity of this specimen is, that while the lower jaw is more elongated than in *Portheus* and *Ichthyodectes*, the maxilla is shorter and deeper.

The portion of the mandible of *Daptinus* figured by Prof. Cope does not enable one to judge of its perfect form; but in the description of the species the jaws are said to be "long and slender;" and in this respect they resemble our specimen. The form of the skull gives us no help in the generic determination; for while the front part agrees very well with the corresponding region of *Daptinus* as described and figured (Cope, *l. c.* p. 214, pl. 47), its hinder parts answer equally well to the description of the same region in *Ichthyodectes multidentatus* (p. 212).

Of the parts which we possess for comparison the jaws appear to be the most characteristic; and as in the form of its mandible our specimen differs more from any known species of *Ichthyodectes* than do the species of this genus from the species of *Portheus*, we are justified in regarding it as belonging to another genus. And, further, as it seems to agree with what is known of *Daptinus,* except in minor points, which may be only of specific importance, it will, perhaps, be best to place it provisionally in this genus.

Daptinus phlebotomus is the only species of the genus at present known; and the specimen described below differs from that in having the teeth longer in proportion to their width, and apparently not so much compressed, while the præmaxilla has only five alveoli, there being, at fewest, nine in *D. phlebotomus.* The intermediate position which our specimen occupies, more especially as regards the flattening of the teeth, between *Ichthyodectes* and the type of *Daptinus*, induces me to propose for it the name of *Daptinus intermedius.*

Daptinus intermedius, new species. (Plate XIX.)

Mandible.—The most striking difference between this mandible and those of *Portheus* and *Ichthyodectes* is the proportional shallowness of its symphysis, and its more elongated form. Its greatest length is 5·3 inches, while the deepest part visible measures 1·2 inch, and the depth of the symphysis is about 0·8 inch. The mandible is partly overlain by the maxilla, which hides the hinder part of the alveolar border, about 2·5 inches being exposed to view; and this contains thirteen teeth, the anterior ones being a little shorter than the others. Between the teeth there are spaces for about thirteen alveoli; but only a few are visible. The outer surface is slightly convex longitudinally, and more distinctly so in a direction at right angles to its length. There is no groove along the lower border. The largest tooth stands 0·25 inch above the alveolar margin, and has a width of 0·1 inch. The crowns are compressed, the inner and outer faces being separated by a moderately sharp cutting edge; but they do not appear to be so sharp or flat as in *D. phlebotomus*, Cope. None of the mandibular teeth have the roots exposed; but most probably they are long and cylindrical, like those of the maxilla. The crowns which are best-preserved have a polished surface, ornamented with very faint traces of longitudinal striations. The articular end of the jaw is shallow, and rises suddenly to the hinder end of the dentary. The form of this part of the mandible is supplied by the right ramus, which is to be seen on the under surface of the specimen, displaced and thrown back to the hinder part of the skull. The suture between the articular and dentary elements cannot be clearly traced, but is probably as shown in the figure. The form of the hinder end of the articulare seems to indicate that there was an angular element. The symphysis, when seen from the side (fig. 1), forms almost a right angle with the alveolar margin; seen from before (fig. 4) it resembles that of *Portheus*, being nearly flat on the inner face, and convex externally; viewed from above it presents two facets, the one directed forwards and slightly inwards, the other almost directly inwards, the junction of the two facets being rounded.

Maxilla.—The maxilla, in proportion to the mandible, is short and deep; its form will be best understood by reference to the figure (fig. 1, *mx*). The greatest width of this bone is towards the front, in the region where, in all probability, it articulates with the palatine. At this part the upper border forms a large rounded process, and, passing backwards, curves rapidly downwards in a regular sweep to its posterior end, which is thin and somewhat broken. The anterior border articulates with the præmaxilla, and probably passes forward on its inner side as in other allied forms. Where the two bones meet, the outer surface is depressed so as to form a shallow groove. The alveolar border is convex from before backwards; and in it are implanted sixteen teeth; between these there are spaces for about sixteen alveoli, several of which are visible. The extreme thinness of the hinder end of the bone renders it very improbable that the teeth ever extended further backwards. The roots of some of the teeth are exposed; and these are nearly cylindrical and hollow. Two or three young teeth are to be seen projecting but little above the alveolar margin. The crowns are mostly broken, but are evidently flattened and sharp-edged, like those of the mandible, which they almost equal in size.

The bone marked *ju* is probably a *jugal*; it may perhaps be one of the suborbital series; but if the latter, one would expect to find the centre of ossification towards its upper border, whereas it is evidently towards the lower and hinder margin.

Præmaxilla.—The side view of the head (fig. 1) shows the præmaxilla in a foreshortened aspect; from above (fig. 2) it is seen to be about twice as long as broad, and of an ovoid form, the oral border being rather wider than the opposite end, which is a little broken. The external surface is convex. The alveolar border has five tooth-sockets; one of these still retains a perfect tooth: in two of them there are roots only, the crowns having been broken off; and in two there are young teeth just appearing above the margin. The broken roots are seen to be circular in section; and two or three of the teeth seem to have been a little larger than those in the maxilla.

Suspensorium and *Pterygo-palatine Arcade.*—The upper part of the *hyomandibular* (*hm*) is widely expanded, and has apparently a very elongated surface for articulation with the skull. The front of this expanded part is attached to the sphenotic; and its posterior angle is connected with the operculum. The lower part of the hyomandibular is only seen upon the outer surface as a long pointed style, lying between the upper part of the præoperculum and the metapterygoid. The bone marked *sym*, which is wedged into the back of the quadrate, is without doubt the *symplectic*; its upper part is covered with pyrites, which prevents its relation to the hyomandibular from being seen.

The *quadrate* (*qu*) bone is a large fan-shaped expansion. Its anterior border and most of the articular condyle are hidden by the extremity of the maxilla and jugal bone. The border which articulates with the præoperculum is thickened; and its hinder part is notched to receive the symplectic element. The third or hinder border is thin, and articulates with the metapterygoid, the junction forming a regular slightly curved line. The upper angle, which is broken, overlaps the entopterygoid (mesopterygoid of Parker).

The *metapterygoid* (fig. 1, *mt.pt*) is a triangular bone, having the lower border in close relation with the quadrate, and its hinder edge articulated with the hyomandibular and symplectic. The front part being broken, its extent in this direction cannot now be known; above and in front it overlaps the mesopterygoid, and sends inwards a horizontal lamina, which forms part of the lower boundary of the orbit.

The *mesopterygoid* (fig. 1, *ms.pt*) is in place; and its outer surface is seen to have been somewhat semicircular in outline, although now partly hidden by the matrix and surrounding bones. The upper margin is slightly concave, and sends inwards a broad horizontal lamina, which, with the similar plate of the metapterygoid, forms the floor of the orbit.

The *palatine* and *pterygoid* bones are not visible; but the mass of pyrites (fig. 1, *pl*) occupies the probable position, and has somewhat the form, of the malleolus of a palatine; and it is quite possible that this bone is merely incrusted with pyrites.

The irregular bone (fig. 1, *na*) lying between the preorbital process of the frontal and the maxilla, from the position which it occupies, seems to be either a somewhat displaced *nasal bone*, or a *preorbital* mucous bone.

Opercular Bones.—The large size of the opercular elements makes them a prominent feature in this fossil. The *præoperculum* has a concave anterior border which embraces a considerable part of both the hyomandibular and quadrate, and extends from the angle of the mandible to within three fourths of an inch of the sphenotic. Its lower and hinder borders, being thin, are somewhat broken; but the general form of the bone may be judged from fig. 1 (*pr.op*).

The *operculum* (*op*) is a large quadrilateral bone, articulating with the hyomandibular by a thickened portion, which is situated near its upper and anterior corner, and from which lines are seen to radiate over the slightly convex external surface. Above the articulation the bone inclines a little inwards and forms a process, which nearly reaches the angle of the pterotic. Below the articulation the anterior border is hidden by the overlapping præoperculum. The hinder free border is nearly semicircular. The lower margin is partly overlapped by the piece of the *suboperculum* which is preserved (*s.op*). The latter bone occupies, as nearly as possible, its normal position.

If this specimen possessed an *interoperculum*, it has been lost on the left side. On the underside of the specimen, however, there is a bone which is probably the right præoperculum; and directly below this there is a broken bone which occupies the position of an *interoperculum.*

Posttemporal.—Immediately above and behind the operculum there is a large flat bone (*pt.tem*), which appears to be an expanded *posttemporal*, occupying, as it does, so nearly the natural position of that bone, and having at its interior portion two processes, such as a posttemporal would be likely to have, for articulation with the skull. It may perhaps be asked if this is not a portion of the operculum of the right side, which has been displaced; but a close examination shows, I think, conclusively, that such is not the case. The edges of this bone are broken; and therefore its precise form is uncertain. Its thickest part is just behind the oblique depression seen in the figure towards its anterior end. The lower edge in this region is produced into a process; and the upper anterior corner seems to have been elongated in a somewhat similar manner. The hinder part is thin; and the outer surface is convex and marked by lines radiating from the thick end of the bone, as shown in the figure.

Skull.—The form and structure of much of the skull can be made out; for the upper surface and left side are almost perfect. The surfaces of the bones are much denuded; but this in some instances affords a clue to their extent. The anterior part of the skull, including the whole extent of the frontals, is comparatively flat, there being no indication of a crest such as exists in this region in some species of *Portheus.* The hinder part of the skull has the sides much depressed, so that the points of the pterotics are on a much lower level than the epiotics or supraoccipital (fig. 1). The *supraoccipital* bears a crest which projects backwards, but does not reach so far in this direction as do the points of the epiotics. Anteriorly the bone is broken, so that one cannot be sure whether it joined the frontals or not; and the small triangular space seen in front of the crest (fig. 2) is due to this breakage. The *frontals* (*fr*) are two large bones, separated by a distinct suture, and forming a considerable proportion of the upper surface of the skull; the right one joins the pterotic (*pt.ot*) and possibly also the supraoccipital (*s.o*); but the boundaries of the bones cannot be traced: the left one has the posterior margin broken away in such a manner as to leave a space between it and the pterotic, and thus displays what appears to be another bone lying beneath, which perhaps may be a *parietal.* I cannot trace any definite division between the last-named bone and the sphenotic (*sp.ot*); but this is not surprising, considering the manner in which other sutures of the skull are obliterated. If I understand Prof. Cope's description of the skull of his Saurodontidæ (*loc. cit.* p. 188), he regards the bone I have marked *ep.ot* as the parietal; but this explanation, for reasons given below, I cannot accept in the present instance. Upon the left side the frontal appears to send down a preorbital process (fig. 1, *p.orb*); but the relations of this process cannot be clearly made out, and it is possible that it may be a process of the prefrontal bone.

Anterior to the frontals, upon the upper surface of the skull, there are two bones (fig. 2) separated by a median longitudinal suture; towards the front of these an osseous band passes across at right angles, obliterating the suture. The whole of these bones may form part of the *ethmoid* only; or, as seems most probable, the parts behind the transverse band may be the *prefrontals*; this, unfortunately, cannot be decided definitely, because the relations of the parts beneath cannot be known, being hidden by the matrix. In a side view of this region (fig. 1) one downwardly directed process is seen to be given off at the transverse band, and another a little further back; the latter is most likely the palatine process of the prefrontal, and the former the process of the ethmoid, which, according to Cope, overlaps the anterior condyle of the maxilla in this genus. The space between these two processes no doubt lodged the olfactory organ.

Bones of the Auditory Region.—The back of this skull presents the five points commonly found in teleostean skulls. The central point is doubtless formed by the supraoccipital, the inner lateral ones by the *epiotics,* and the outer ones by the *pterotics.* Prof. Cope, as already stated (*l. c.* p. 188), seems to think these inner points in the Saurodontidæ are the parietals; but we should naturally expect, if this were so, that the lines indicative of the direction of growth would radiate from some anterior portion of the bone, whereas in this specimen they radiate from its extreme posterior angle; and, further, the inner lateral process of the fishes' skull is usually believed to contain part of the superior vertical semicircular canal, and the normal place for the epiotic is upon the summit of this canal. The bone occupying the usual position of the *pterotic* is large, and extends a long way up towards the middle line of the skull, the radiating lines passing upwards and forwards from the hinder and outer portion. The extent of this bone is shown best in fig. 1 (*pt.ot*); the edges on the left side are broken, and, as here represented, may possibly include part of the parietal. When perfect, as on the right side, the pterotic appears to join the frontal and to cover much of the epiotic; the sutures, however, cannot be traced. The postorbital process occupies the position of the *sphenotic*; and its lower and proximal part gives attachment to the hyomandibular. Within the orbit, and well under the skull, there is a bone which seems to join the sphenotic, and may be the *alisphenoid*. The other parts of this region are not visible.

Vertebræ.—The bodies of five vertebræ have been exposed, although only four of them are visible in a side view (fig. 1). In general form and structure they agree with those of *Portheus*, the bases of the neural arches being lodged in deep depressions; and the heads of the ribs, or perhaps ossicles intervening between the ribs and the vertebræ*, appear likewise to be inserted in similar depressions; and there are lateral depressions between the ribs and the neural arches. The vertebra marked 7 is the most perfect, and is probably the seventh from the skull. This vertebra has a long deep depression on the side, situated a little below the base of the neural arch, and a much smaller one just below the hinder end of the larger one. The centrum is proportionally longer than in *Portheus gaultinus* (vol. xxxiii. pl. 22. f. 10), being about 0·65 inch long and 0·5 inch high. The vertebra marked 6 has lost the small lateral depression; and the rib-ossicle, which is covered with pyrites, extends further up the side of the centrum.

Daptinus, species?

There is a right maxillary bone, also in the British Museum (no. 42017), from the Lower Chalk of Dover, which agrees so closely in form with the maxilla of the specimen above described, that there can be little doubt of its belonging to the same genus. The specific identity of the two specimens, however, is very questionable; for this maxilla has the outer surface ornamented with fine granulations and pittings. The hinder portion, where probably it was overlapped by a jugal, wants these markings, and presents instead a few large oblique undulations or ridges.

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* Prof. Cope states (*l. c.* p. 207) that, in *Ichthyodectes anaides*, these depressions accommodate short ossicles, to which the ribs are attached; and it is possible that the same arrangement may obtain in the present instance also.

EXPLANATION OF PLATE XIX.

Daptinus intermedius, n. sp.

den. Dentary bone of mandible.
a. Transverse section of a tooth.
art. Articular bone of mandible.
mx. Maxilla.
p.mx. Præmaxilla.
eth. Ethmoid.
pr.fr. Prefrontal.
fr. Frontal.
pa. Parietal?
s.o. Supraoccipital.
ep.ot. Epiotic.
pt.ot. Pterotic.
sp.ot. Sphenotic (or postfrontal).
a.s. Alisphenoid?
h.m. Hyomandibular.
mt.pt. Metapterygoid.
ms.pt. Mesopterygoid (or entopterygoid).
qu. Quadrate.
sym. Symplectic.
pl. These letters are placed upon some pyrites which probably covers the palatine.
na. Nasal bone?
ju. Jugal?
pr.op. Præoperculum.
op. Operculum.
s.op. Suboperculum.
pt.tem. Posttemporal.
3, 6, 7, 8. Vertebræ.

The letters have the same signification in all the figures.

Fig. 1. View of the left side of the head, with vertebræ, &c. Two thirds natural size.
2. Skull, seen from above, with left præmaxilla and maxilla.
3. View of skull from behind, to show the manner in which the sides are depressed; natural size. In this view the skull is almost hidden by the matrix.
4. The symphysial surface of mandible, seen from before.

Discussion.

Mr. Etheridge remarked on the character of the work done by the author, and called attention to the interesting specimens still remaining undescribed in some of the museums of this country. Many of the fish-remains from the English Chalk are well worthy of careful study by competent ichthyologists.

Fig. 2.

Fig. 3.

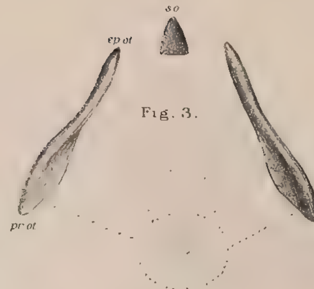
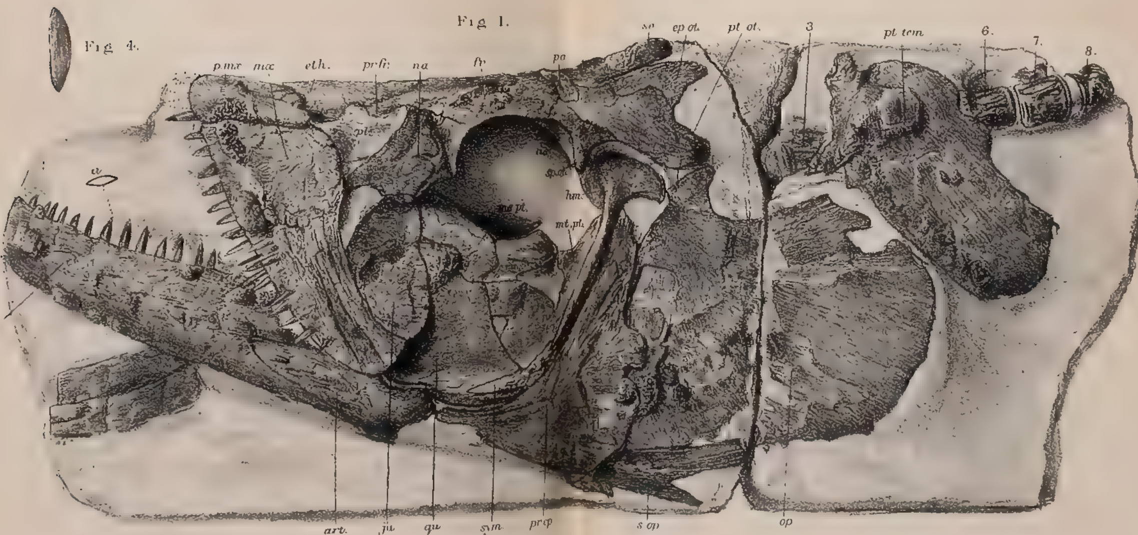


Fig. 4.

Fig. 1.



R Mintern lith.

Mintern Bros imp.

DAPTINUS INTERMEDIUS.

28. *The* Submarine Forest *at the* Alt Mouth.

By T. Mellard Reade, Esq., C.E., F.G.S. (Read March 20, 1878.)

On the shore at Great Crosby, Lancashire, stretching, at irregular intervals, for a space of about a mile nearly due north from a stream of water called Thornbeck Pool, are the remains of a forest, which have from time to time attracted considerable attention. It has been described by various observers, the earliest mention I know of being in the 'Gentleman's Magazine' for 1796, p. 549, accompanied by an engraving, giving all the salient points which still distinguish the forest-bed. A view of these submarine forestal remains also forms the frontispiece of the memoir by Mr. C. E. De Rance on the "Superficial Geology of West Lancashire," lately published by the Geological Survey. I have also described it in my paper on the Postglacial Geology of Lancashire and Cheshire*.

As it has been pretty roundly asserted by some local observers that neither these trees nor those of the equivalent bed on the Cheshire shore are *in situ*, though I had no doubts of the fact myself, to set the question at rest I invited several gentlemen†, most of them members of the Liverpool Geological Society, to be present on the 19th of January, 1878, at the digging-out and uprooting of one of the stools of the trees, which are now rapidly diminishing in number by the denudation of the sea.

A low stump was selected which had an oak trunk lying by it in a N.E. by E. direction, to all appearances in the position in which it had rotted off and fallen from its rooted base.

A trench was cut round the stump; and the portion isolated by it, in which the stump was situated, measured 7 feet 6 inches by 2 feet 6 inches.

The trench was about 1 foot 6 inches wide at the top, and 2 feet 2 inches deep from the surface. It was cut through 1 foot of peat and 1 foot 2 inches of blue clay. The operation was closely watched; and roots were cut through all round, which ran along near the surface of the clay, and penetrated it diagonally, while rootlets and tap-roots descended vertically below our excavation into the blue clay below. To make the investigation complete, we carefully pared the clay and peat from about several of the main roots, and traced them from the stump directly into the blue clay, until every one of the party was fully satisfied that the stump was in the position in which it had grown. This being done, by the aid of a couple of planks and the undermining of the stump, we levered it up, when numerous root-sections were visible in the clay below on the stump being turned over. I had the trunk and

* 'Proceedings of Liverpool Geological Society,' session 1871–72.

† Messrs. R. A. Eskrigge, F.G.S.; W. Semmons, F.G.S.; T. J. Moore, C.M.Z.S.L.; Thos. Higgins, F.L.S.; Alfred Morgan; E. M. Hance, LL.B.; Edwin Foster; and W. Hewitt, B.Sc.

as much of the stump and attached peat and clay as could be got into a cart taken away and deposited in my garden, where the portions now lie. I have since traced the ramification of the roots through the clay on the remains in my possession. While this was going on, some of the party were digging round the stool of a larger oak tree, which had been broken off about 2 feet 6 inches above the surface of the peat. In this case also they traced the main roots into the ground below the peat, which was of a more sandy nature than in the example just described.

The oak timber in all cases is very black; and portions of it in the trunk are quite sound; but the roots are invariably spongy and rotten; and it was interesting to see, as the root penetrated the ground, that the sections of it cut by the spade became of a much lighter colour. I find on exposure to the air they get darker.

Attached to the trunk on the lower side is a portion of the peat, showing that, before it fell, there had been an accumulation of vegetable matter. I have subjected portions of it to a microscopic examination: it is very much decayed and compressed, but appears to be composed largely of bark, leaves, and twigs. The condition of the base of the prostrate trunk is soft and spongy, of a dark brown colour, and precisely corresponds with the wood of the top of the stump. The second stump also showed the same change downwards as the roots were approached; and when the roots were cut through with the spade they were undistinguishable in colour and condition from those in the first example.

The stump dug out was situated about 6 or 7 feet above Ordnance datum, and was covered by most tides. Formerly the peat and trees extended a long way down the shore towards low-water mark, as shown by several outliers still in existence, but what remains is being rapidly destroyed.

29. *The* Chronological Value *of the* Pleistocene Deposits *of* Devon. By W. A. E. Ussher, Esq., F.G.S., of H.M. Geological Survey. (Read December 19, 1877.)

[Communicated to the Geological Society by permission of the Director-General of the Geological Survey of the United Kingdom.]

Part 1. Deposits.

A. (*α*) The high tableland of the Cretaceous area of the Blackdown Hills and the summit of its outlying landmark, Haldon Hill, are capped by an accumulation of brown, yellowish, or grey clay full of broken unworn fragments of flint and chert. The clay rests alike on Chalk and Greensand in pipes *. Its character in Chalk districts is almost identical with that of the clay with flints in Kent; but near the westernmost extension of the Chalk (to the east of Sidmouth) the contained flints are seldom whole. In many places the matrix is thickly crowded with small flint chips and powder, giving it a grey colour and gritty texture, as on Haldon and Peak Hill, near Sidmouth. The clay with flints is confined to tableland areas: where the contour has been subsequently modified, it is only found on such heights as exhibit the original surface of the old plain from which they were isolated. The clay with flint and chert varies in thickness up to nearly 50 feet.

That it has suffered from denuding agencies is testified by the presence of

(*β*) Waterworn fragments of flint on its surface, bearing somewhat the same relation to the clay with flint and chert that is presented by the brick-earth to its representative in the south-eastern counties. This waterworn material is of very local occurrence on the Cretaceous tableland; upon Haldon it has been described by Mr. Godwin-Austen † and others.

(*γ*) A patch of flint- and quartz-gravel rests on the Triassic breccia near Colford in the Crediton valley.

(*δ*) Near Staple Hill, on the north summit of the Blackdowns, I found a patch of worn flint- and quartz-gravel, containing also fragments of that dark slaty grit noticeable in the scattered waterworn materials on Haldon. This gravel appears to rest directly upon Greensand.

The Cretaceous materials of Orleigh Court, described by De la

* In chapter 13 of De la Beche's 'Report on the Geology of Cornwall' &c., and in Mr. Godwin-Austen's "Geology of South-east Devon" (Trans. Geol. Soc. ser. 2, vol. vi. p. 440 &c.), the most general accounts of the Pleistocene deposits are given. In Mr. Pengelly's numerous papers on the cavern deposits, raised beaches, and submerged forests of Devon, to be found in most of the yearly volumes of the 'Transactions of the Devon Association,' a partial sequence of the events transpiring during the later stages of the Pleistocene epoch has frequently been put forward.

† Trans. Geol. Soc. ser. 2, vol. vi. p. 447.

Beche * furnish another example of the excessive amount of Post-cretaceous denudation to which the country has been subjected.

(ε) The sands skirting the Bovey valley and resting in a conformable mantle on its slopes have been briefly described by Mr. Woodward †. They were formerly regarded as of Cretaceous age. Bits of flints have been occasionally found in them.

(ζ) Upon Straightway Hill, near Ottery St. Mary, De la Beche ‡ gives a section of pebble-gravel exhibited in one of the pebble-bed pits, either the result of decomposition *in situ* or of early fluviatile redeposition.

Thus far I have noticed deposits whose sites indicate a period of formation disconnected with the present lines of drainage.

B. (*a*) In all the broad valleys of Devon patches of gravel occur, capping hills here and there or resting on their projecting slopes. These are often fragmentary, and exist only as soils; but in many places gravels occur at heights exceeding 50 and sometimes 100 feet above the neighbouring alluvia §. Such gravels are to be found in Exeter, Tiverton, near Wellington, Stoke, Cannon, and many other places.

At lesser heights than 30 feet above the alluvia, terrace-like gravels are occasionally exhibited. Near Ottery St. Mary two old gravel terraces are visible. At the 'Blue Ball' Inn, in the valley of the Sid, in the Exe valley between Bickleigh and Exmouth, in the Axe valley near Axminster &c., gravel deposits flank the alluvial flats in places and gently slope down to them. On the Triassic cliffs several patches of old river-gravel are exposed between Dawlish and Budleigh Salterton, belonging to a period in which the sea-board and inland contour were very different, though undergoing those modifications which led to their present relations.

Many of the small brooks of Devon are bordered by considerable alluvial flats ‖ far from the present main arteries of drainage.

(*b*) Thick deposits of Postmiocene clay are found in the Bovey valley; at Petrockstow whitish and pale grey clays have been found to extend to a depth exceeding 70 feet.

Near Barnstaple Mr. Maw ¶ notices the occurrence of tough smooth brown clay, 78 feet in thickness, superimposed on a gravelly beach similar to that exposed at Fremington, the surface of the clay being at an elevation of 100 feet above the sea at Roundswell, between Fremington and Tawstock. In Tawstock Park the same observer noticed from 25 to 30 feet of clay on shingly

* Report on the Geology of Cornwall and Devon, p. 249.

† Quart. Journ. Geol. Soc. vol. xxxii. No. 127 (Aug. 1876), p. 230; also in 'Geology of England and Wales,' p. 317.

‡ Report &c., p. 236.

§ *Vide* paper by E. Parfitt, Trans. Dev. Assoc. for 1876, p. 162.

‖ R. A. C. Godwin-Austen, "Geology of S.E. Devon" (Trans. Geol. Soc. 2nd ser. vol. vi. p. 439).

¶ "On a Supposed Deposit of Boulder-clay in Devonshire" (Quart. Journ. Geol. Soc. vol. xxi. pp. 447); Geol. Mag. vol. ii. p. 473.

gravel. At Combworthy a trap boulder was found in the clay, which was capped by gravel.

The probable contemporaneity of the Fremington gravels with raised beaches would lead one to regard them as of estuarine origin.

(*c*) Boulders * of large size are frequent in the old gravels of the Teign and Dart; but whether well worn or faintly subangulated, ice-markings have, so far as I am aware, never been detected upon them.

(*d*) The occurrence of raised beaches is confined to the older-rock coast-line. The fine examples at Hope's Nose and Saunton Burrows have received much attention †. Their height above the sea is remarkable, as those on the Cornish coast seldom exceed 10 feet above high-water mark on the strand adjacent, and the traces of old beaches near Start and Prawle Points and at Sharkham Point and Slapton Ley do not furnish exceptions to the rule.

(*e*) On the Palæozoic coast-line of Devon, as well as Cornwall, the cliffs are frequently capped by angular stony débris, consisting, so far as I have observed, of such material as would be afforded by the adjacent rocks. This angular accumulation is imbedded in a brown or reddish-brown loamy clay. Where raised beaches and stony loam are exhibited in the same cliff, the latter invariably overlies the former. An apparent anomaly is furnished by the raised beach near Prawle Point, to which Mr. Pengelly assigns two different periods of formation with an intervening period of waste. From an examination of the section I am disposed to regard the apparent separation of the upper from the lower exposed portions of the beach as due to a concealing mask of talus from the accumulation above, partially obscuring the section.

In inland districts the subjacent rock is frequently concealed by a thick soil with unworn stones, the harder portions of the disintegrated strata; this may in places be contemporaneous with that on the coast, and referable to the same period of meteoric waste. To this angular accumulation the general term of "Head" is applied.

(*f*) Traces of submerged forests ‡ have been noticed in Torbay, Bigbury Bay, at Blackpool, near Dartmouth, on the north and south sands in Salcombe estuary, at the mouth of the Char§, and at Westward Ho. In most cases the vegetable matter is associated with bluish leaden-coloured clay. Mr. Pengelly mentions the discovery of bones of *Cervus elaphus*, *Sus scrofa*, *Equus caballus*, *Bos longifrons*, and *Elephas primigenius* in the relics of the Tor-Abbey, Goodrington, and Broad-Sands portions of the Torbay forest.

* 'Geology of England and Wales,' by H. B. Woodward, p. 317; Ormerod, Quart. Journ. Geol. Soc. vol. xxiii. p. 418 &c.; Ussher, Trans. Dev. Assoc. for 1876, "On old Gravels of River Dart."

† Trans. Geol. Soc. 2nd ser. vol. v. pp. 279, 287; Quart. Journ. Geol. Soc. vol. vii. p. 118 *et seq.*; Trans. Dev. Assoc. for 1867, p. 43; Student, vol. iv. p. 338 *et seq.*

‡ Trans. Dev. Assoc. for 1865, part iv. p. 30; for 1866, part v. pp. 77, 80; for 1868, vol. ii. p. 415; for 1869, vol. iii. p. 127.

§ De la Beche's 'Report' &c., p. 417.

Mr. H. Ellis* mentions the probability of some mammalian bones and teeth washed ashore at Northam having been derived from the submerged forest in that locality, Westward Ho. On Sidmouth beach a stratum of blue clay is sometimes exposed after severe gales through displacement of the shingle-beach; two teeth of *Elephas primigenius* were obtained from this clay by Mr. P. O. Hutchinson†, and are now in the Exeter Museum. In the Torbay, Blackpool, and Westward-Ho forests the presence of roots and rootlets in the clay leave no doubt as to the growth of the forest *in situ*.

(*g*) The present valley-bottoms exhibit in the lower reaches of the rivers considerable breadths of flat alluvial land, through which the present rivers flow. The gradual upward rise of these alluvia in places, terminating in gravel terraces at some feet above the river-banks, connects the last stages of fluviatile action in the elaboration of the valleys. The estuarine conditions of rivers being so largely dependent on slight physical and local alterations, and so much influenced by human agency, it seems almost possible to explain such recent alterations as are evidenced by the remains of *Tellina*, *Mactra*, *Cardium*, &c. in the alluvium of the Exe near Alphington ‡ without invoking oscillations of level.

A somewhat similar occurrence was observed by Mr. Pengelly at Torquay §.

From the occurrence of similar phenomena in Cornwall I am disposed to concede a slight amount of oscillation in the downward movement which led to the submergence of the forest tracts.

Part 2. Sequence of Deposits and of Physical Changes.

Owing to the want of trustworthy evidence respecting the westward extension of the Tertiaries, and the vicissitudes experienced by Devonshire during the Glacial period, its early Pleistocene geology is at present very indefinite. The gravel near Staple Hill (δ), on the Blackdowns, if not of Tertiary age, is probably the oldest deposit resulting from the redistribution of Tertiary beds.

The waterworn materials on Haldon and the Blackdowns (β), probably in part resulting from a redistribution of Tertiary gravels, carry us back to a period anterior to the initiation of the present drainage-system.

From its mode of occurrence, the clay with flints (α) evidently dates its origin from a period of sufficient antiquity to allow of the union of the Cretaceous deposits of the Blackdowns with Haldon, and probably to a time when the Cretaceous districts abutted on the slopes of the Quantocks.

In the general Table of results appended to this paper I have put

* Trans. Dev. Assoc. vol. ii. p. 162; Rep. Brit. Assoc. for 1867, Trans. of Sections, p. 59.

† Trans. Dev. Assoc. vol. iii. p. 143 (1869).

‡ Trans. Geol. Soc. 2nd ser. vol. vi. pp. 440, 441.

§ Trans. Dev. Assoc. vol. ii. p. 164 (1867).

forward a very hypothetical explanation of the production of the clay with flints. Mr. Whitaker's theory * of simple decomposition of the Chalk seems to me to be insufficient to explain the fracture of the flints to depths of 30 feet below the surface, and to account for the lie of the substance on the Greensand, and for the absence of the clay in Cretaceous districts not forming parts of the tableland area. My solution is only a tentative hypothesis, for which I have not got sufficient corroboration to be a warm advocate.

The gravels of Orleigh Court and Colford, resulting in part from the redistribution of Cretaceous materials, were deposited during the earlier stages of the excavation of the present drainage-system. The sands flanking the Bovey valley (ϵ), and conforming to its slopes, form another Posttertiary problem. Owing to the high incline on which they lie, it does not appear probable that the adjacent country during their deposition presented its present relative levels, but that movements of upheaval and depression of local irregularity, aided, perhaps, by such dislocations as the fault pointed out by Mr. Pengelly in the lignitiferous beds of Bovey (producing a downthrow of 100 feet), may have materially altered the contour of the ground.

The pebble-gravel on Straightway Hill (ζ), if not merely the result of the decomposition of the subjacent Triassic pebble-bed, appears to have been formed after the breaking-up of the Cretaceous plain and the initiation of the larger valleys, but before the lines of present drainage had been elaborated. How far other gravelly beds of the Trias may have been thus redistributed it is impossible to say.

We now come to the river-gravel period, after the selection of the present lines of drainage, but before all the valleys had been excavated to their present depth.

In speaking of the excavation of the valleys I would not be understood to mean that that operation was absolutely synchronous in different parts of the area, nor that it was uniform in progress: some valleys may have been initiated in very early Pleistocene times; others, in Palæozoic districts, may have been of Triassic or Cretaceous age, and merely reexcavated. The relative magnitudes and velocities of the rivers, and the constitution of the rocks through which they flowed, would always exercise a material influence on the production of the contour. From the beginning of this gravel-period the process of fluviatile erosion seems to have gone on uninterruptedly. The rivers would appear to have exhibited much greater force and volume than those of the present day; for their gravels exist in a fragmentary condition, capping hills or mixed with soils on slopes parallel with the present lines of drainage, but seldom exhibiting distinct terrace-like characters, which they would have done had the water-channels been as impotent to carry off large masses of material as those of the present day.

* Memoir illustrating Sheet 13 of the Geological-Survey Map, pp. 54, 55; also Sheet 7, pp. 64, 65.

In parts of the Exe and other valleys terraces of old gravel are noticeable, but generally at no great heights above the alluvial valley-bottoms, and in a fragmentary condition.

Taking into account the large amount of tributary erosion and great subaerial waste during a long period, the fragmentary state of the old river-gravels is not remarkable.

In this period we must include the formation of the raised beaches and the accumulation of the angular stony loam or "head."

The nature of these deposits, of which the raised beaches are the oldest (as Mr. Carne pointed out years ago *), furnishes a valuable indication of the physical changes which were in progress for at least a part of this period of fluviatile erosion. Although certain signs of raised beaches are not discoverable on the Triassic cliff-line, owing to its rapid waste, many of the gravels both on the present Triassic cliffs and in inland localities may be fluviatile equivalents of beaches then forming, and, in some cases, contemporary estuarine deposits, as at Par, in Cornwall, where estuarine gravels contemporaneous with an adjacent raised beach are shown.

The gravels shown in the Fremington railway-cutting were probably an estuarine deposit of the Taw. It would appear that during the earlier stages of the gravel-period the land was at a much higher level than at present, but gradually sinking till the formation of the raised beaches marked the close of the subsidence, at heights seldom exceeding 20 feet above the sea-level, but locally attaining to 60 feet or more above that level, as evidenced by Hope's Nose and the old beach of Barnstaple Bay. Whether the exceptional height of these beaches may be partly due to unequal subsequent elevation, partly to unequal rise of tide during their formation, I leave for conjecture, as also whether the Lithodomous perforations and high-level marine terraces described by Mr. Pengelly † in the neighbourhood of Torquay afford satisfactory evidence of the subsidence, in that part of Devon, of heights exceeding 200 feet above the sea-level during the Pleistocene period.

If such a subsidence took place, it must have been confined to the locality in which the observations were made; otherwise many of the inland gravels would be marine; and of this, either in assortment or the presence of marine shells, we have no evidence whatsoever.

The movement succeeding the old beach-formation was one of elevation, proceeding, at any rate, to the heights at which they are at present found above the sea ‡. Here two phenomena step in, viz. the "head," forming cliff-faces in some parts of the Palæozoic coast-line for as much as 100 feet in vertical height; and the submarine forests. Whether the Head be due to intense cold and excessive surface-waste, or to a less rigorous climate, its position and

* Trans. Roy. Geol. Soc. Cornw. vol. iii. p. 238.

† Trans. Dev. Assoc. part v. p. 82 (1866).

‡ Their further elevation, at least near Padstow in Cornwall, is proved by the existence of an old consolidated beach on the Doombar Sands at some feet below high-water mark in the vicinity of a raised beach some feet above that datum.

character are very distinct from the present accumulation of talus, and indicate changes both in climate and physical geography.

In climate—because such a quantity of material in sites not now favourable for its accumulation could scarcely be ascribed to ordinary subaerial waste; more marked seasons, sharper frosts, and a heavier rainfall would have been more favourable to its production.

In physical geography—because, from the position of the Head on cliff-faces almost immediately backed by rocks rising in crags a few yards inland from the top of the cliffs, as near Start Point, and its isolation in pinnacles resting on rocky pediments separated by from 30 to 60 yards of beach from the present cliffs, as near Start Point and on Godrevy beach in Cornwall, a further elevation of the old beach platform on which it often rests must have taken place to allow of its accumulation undisturbed by storm-waves or spring-tides.

The traces of submerged-forest lands on the coasts of Cornwall and Devon prove the elevation of the raised beaches to have been carried to much greater heights above the sea than they are now found at. The Head is more easily accounted for by the admission of a colder climate, which would hardly have suited the forest-growth; so that an accompanying elevation is naturally suggested. That elevation may have culminated in continental conditions; and some of the former denizens of the caves may have migrated to and fro as the climate favoured them; and Alpine *Salices* * may have been indigenous.

In inland districts many of the existing thick stony soils may have been due to the subaerial waste of this period, and, if exposed in a cliff-section, would be, in most cases, undistinguishable from the coast Head.

Torrential streams and brooks frequently exhibit trifling strips of alluvia of somewhat similar character to the Head; nor does it seem improbable that the regularity and definite arrangement of the fluviatile deposits was interrupted from time to time through the fluctuations of climate causing the prevalence of floods and hasty or broadcast distribution of abraded materials, so that their relics would be mistaken for soils resulting from decomposition of the subjacent rock *in situ*.

The clays of Roundswell and the Head in the Bovey valley might be classed in this period and regarded as roughly contemporaneous with the Head; but the Petrockstow deposit may be of much older date.

In bringing about the present state of things, a gradual subsidence, accompanied by an ameliorating climate, brought the period of great subaerial waste to a close, and favoured the growth of forests on the old sea-bed left dry by the precedent elevation. Accordingly forests flourished beyond our present coasts, and, as the amelioration proceeded, may have covered the interior. Little by little the blasting effect of the advancing waves on the growth of timber, and the cir-

* Pengelly, "Notes on Recent Notices of the Geology and Palæontology of Devon," Trans. Dev. Assoc. for 1874.

cumscription of the belt of forest-land, produced swamps and morasses near the sea-board, which, with the decaying timber, were finally entombed as the sea regained its old cliff-bounds.

In inland localities the forest growth died out, leaving few traces except in vegetable mould, peaty soil, or tree-trunks, as at Bolventor, in Bodmin Moor, Cornwall, and in some of the river-valley alluvia of Devon.

During, and probably for some time previous to, the growth of the forests, the broad alluvial tracts in many of the valley-bottoms were being formed; but the decreasing rainfall no longer supplying an adequate quantity of water, the dwindling streams expended their energies in the excavation of their present courses in their old deserted beds, whilst the sea was cutting back the soft Secondary cliff-line to its present bounds.

Such, so far as I can read them, are the changes indicated by the Pleistocene deposits of Devon. The life-history of that period, as furnished by the caves, would be well worthy of an independent perusal; owing to the impossibility of correlating cavern-deposits with those *sub cœlo*, and to an imperfect knowledge of the subject, I have not attempted any absolute correlation.

The following Table embodies the results arrived at:—

Period.	Deposits.	Changes indicated.	Corresponding to
PREGLACIAL.	? Gravel patch on north summit of the Blackdowns. ? Old bone-breccia of Kent's Cavern in part.	Probable extension of subsidence to south-western counties during late Tertiary times. Approach of cold.	Preglacial.
GLACIAL.	Clay with flint and chert considered as portions of a metamorphosed ice-bed. ? Part of the Bovey-valley clays. ? Clay of Petrockstow in part. ? Old bone-breccia of Kent's Cavern (in part) and crystalline stalagmite.	Snow accumulating on the high lands. Formation and descent of glaciers as the cold increased, finally becoming confluent and debouching in an ice-field upon a district chiefly composed of Cretaceous and probably Tertiary strata, planing its surface. Gradual amelioration of climate, and disappearance of ice. Liberation of large quantities of surface-water from melting ice &c. Thorough redistribution and removal of then-existing Tertiary outliers. Partial destruction of upper part of old ice-bed, and removal of its moraine rubbish. Removal of much Secondary strata from Palæozoic districts.	First Glacial Period.
	I. Old gravel patches of Colford and Orleigh Court; waterworn materials on the Blackdowns and Haldon; sands flanking the Bovey valley. ? Redistributed Triassic pebble-beds of Straightway Hill &c. ? Cave-earth of Kent's Cavern (in part).		Glacial. EPOCH.

Period.	Deposits.	Changes indicated.	Corresponding to
Postglacial.	II. Fluviatile period, gravels connected with the formation of the present valley-system, and occupying sites indicative of its gradual elaboration, during which the raised beaches were formed, and the "head" accumulated. ? Cave-earth of Kent's Cavern (in part). ? Granular stalagmite of Kent's Cavern. ? Clay of Petrockstow in part. Clay of Roundswell, near Barnstaple.	Land higher than now, but sinking. Devon experienced different meteorological conditions from the present, the streams being of greater volume. Culmination of subsidence at from 10 to 60 feet above the sea-level, marked by Raised Beaches. Elevation gradually producing greater cold, more marked seasons, and searching winter frosts, leading to much waste of exposed rock-surfaces, floods, &c. Probable culmination of the elevation in continental conditions admitting of the migration southward of a temperate fauna and the advent of one requiring cold temperate conditions.	Intra-Glacial. Second Glacial Period.
Postglacial.	III. Submarine forests. Most of the river-valley gravels and alluvial tracts bordering the present river-courses. IV. The present.	Most of the valleys excavated to nearly their present depths during the earlier stages of an ensuing subsidence which led to conditions favourable to forest-growth upon the old marine plain and, later on, in inland localities. The gradual circumscription of the forest belt by the advancing sea and diminishing rainfall led to the formation of swamps in maritime districts. The desertion of their old channels by the dwindling streams and the excavation of new courses in them, whilst the sea finally entombed the forests and swamps on the coasts and produced the present cliff-line.	Postglacial.

The Postglacial deposits, as will be seen in the foregoing Table, have been divided into three sub-periods. That these are only considered Postglacial as regards Devon will be seen from the last column, where a rough correlation with the glacial vicissitudes experienced by other parts of Britain has been attempted.

Unless we regard the clay with flint and chert as the relics of an ice-bed metamorphosed *in situ*, from which all morainic débris had subsequently been swept away, I know of no signs of the former existence of land-ice in Devon. On the other hand, there is no indication of a glacial submergence.

Yet the accumulation of the "head" seems to indicate the effect of the last throes of the Glacial epoch (second glacial period) on the climate of Devon; therefore the maximum intensity of glacial conditions must have produced a corresponding effect on Devon.

Ignoring the hypothesis of glaciation put forward in the above Table, a great snowfall and very penetrating frosts may at least be invoked. From such agents and from the liberation of large quantities of surface-water during fluctuations of climate, a much greater surface-waste than that of the Head-period would result. The redistributed relics of such a period would be undistinguishable; but the fracture of flints to considerable depths from the surface and the intrusion of earthy matter might be referred to it, though other difficulties presented by the clay with flint and chert are not so easily solved.

Discussion.

Mr. Belt thought that sufficient reason had not been shown for ascribing a Tertiary age to any of the surface deposits. At Bovey Tracey lignites of Miocene age occupy the bottom of the valley, and have been proved to extend to at least 50 feet below the present level of the sea. The valley had therefore been excavated to more than its present depth in Miocene or Premiocene times. The Miocene deposits were covered with drift-gravels, boulder-beds, and clays. In the latter the remains of Arctic plants had been found. The drift-gravels mantled the slopes of the valley, as had been shown by Mr. H. B. Woodward, and they reach at least up to a height of 500 feet above the sea. The tops of many of the hills are also covered with a drift-deposit containing far-transported boulders, as had been described by De La Beche, Mackintosh, and others. In Somerset, Mr. H. B. Woodward had recorded the discovery of a tooth of a Rhinoceros in these drift-beds on the Oolitic summit of King's Down; and in Dorsetshire, Prof. Prestwich had described the occurrence of bones of *Elephas antiquus*, *E. primigenius*, and other mammals in the drift-gravels on the hill at Portland Bill, 400 feet above the sea. All these drift-beds, whether in the bottom of the valleys or on the slopes or tops of the hills, were thus clearly shown to be of Posttertiary age; and it remained for those who held that the gravels had been deposited as the valleys were being excavated to explain their presence up the slopes and on the tops of the hills bounding the Bovey-Tracey and Teign valleys, when it was evident that these valleys were in existence in Miocene times. To him it appeared certain that the hills in the Glacial period had been covered with water, over which the far-transported stones had been carried on floating ice.

Mr. Whitaker said that he had been requested by Mr. Ussher to state that his views were theoretical as to the earliest conditions of these Pleistocene formations. With regard to the clay with flints, every conceivable theory had been broached by French writers, one of whom has lately brought forward a theory similar to his own. The author's reasons for his notions of the period intervening between that of the raised beaches and that of the sunken forests were derived from investigations carried out, not only in Devonshire, but also in Cornwall. He inquired whether Mr. Belt maintained that the gravel went up the hillsides continuously, or only in patches.

30. *On the* Chronological Value *of the* Triassic Strata *of the* South-western Counties. By W. A. E. Ussher, Esq., F.G.S., of H.M. Geological Survey. (Read March 20, 1878.)

[Communicated by permission of the Director-General of the Geological Survey of the United Kingdom.]

In no part of the south-western counties is a more detailed section of the Triassic rocks exhibited than on the South-Devon coast. It is the district in which the subdivisions seem to have attained their maximum thickness; and though they may be traced in unbroken conformity to Williton, near the shores of the Bristol Channel, the absence of the lower members of the group to the east of Taunton, and a study of the variable relations of land and water during the period in different parts of the area, render the proof of the following propositions a necessary supplement or second part of the paper which I have already had the honour of communicating to the Society *.

First proposition.—That the South-Devon and West-Somerset Triassic area was not connected with that of Gloucester and the midland counties till the later stages of the Keuper period.

Proof.—(*a*) The tailing-off of Triassic sediments towards the Mendip country.

(*b*) The representation of the Trias on the north of the Poldens by marls alone, the Dolomitic conglomerate being a contemporary beach.

(*c*) The abnormal thinning-out of the Trias on the north of the Mendips. Thus at Tyning pit, near Radstock †, it was bottomed at 186 feet; at Norton-Hill pit at 172 feet; at Batheaston (under Rhætic) at 54 feet; in Mangotsfield cutting at 25 feet. The general results arrived at by Mr. Moore give an average thickness of 50 feet to the Trias within the coal-basin.

(*d*) The fact that these marls, being in every case the directly antecedent deposits to the Rhætic beds, must be the equivalents of the Upper Keuper Marls of the midland counties, whilst their attenuation in the intervening districts proves the non-existence of connexion between the Triassic areas of the midland counties and those of West Somerset and Devon till a late stage in the deposition of the Upper Keuper Marls.

Second proposition.—That the area east of Taunton and south of the Quantocks was not submerged before the deposition of the Lower Keuper Sandstone and probably not till the later stages of its formation, the Quantocks acting as a barrier between the earlier deposits in the Bridgewater area and those of the Watchet valley.

Proof.—(*a*) The Trias of Taunton Vale is composed of Upper Keuper Marl, beneath which sandstones are visible on the south flanks of the Quantocks in places.

* Quart. Journ. Geol. Soc. vol. xxxii. p. 367.
† *Ibid.* vol. xxiii. p. 458.

(*b*) These fringing sandstones, being prolonged either way, are found to be the upper portions of the subdivision extending from Sidmouth and Otterton Point to Williton, and on the other hand to pass downwards into the Wembdon breccia in the Bridgewater district.

(*c*) From the fact that no beds of sandstone, not distinctly referable to the Upper Keuper beds, have been hitherto exposed in sections in Taunton Vale except those fringing the Quantocks.

(*d*) It is difficult to say whether the Bridgewater sandstones are the base of the Trias in that district: if not, there is no possibility of correlating the beds subjacent with the regular sequence of deposits in the West-Somerset and South-Devon areas.

Third proposition.—That a subsidence progressing from south to north led to earlier deposition in South Devon and to a consequent attenuation of the Lower beds towards Watchet and Porlock, between which places their continuity cannot be shown.

Fourth proposition.—As a consequence of the preceding the lowermost beds of the south-coast Trias far exceed their more northerly equivalents in thickness, and afford a strong probability that a reconstruction of the English-Channel valley would exhibit a still greater development of beds, dating perhaps as far back as late Permian times.

Proof.—(*a*) The gradual attenuation of the area occupied by beds below the Upper (Lower Keuper) Sandstones proceeding northwards from Tiverton junction.

(*b*) The less perfect representation of the bottom beds as we recede from the south coast, their comparative homogeneity in many places, and the absence of any strata in the subdivision, even in the Crediton and Tiverton valleys, equivalent in thickness to the breccias and breccio-conglomerates between Dawlish and Babbacombe.

(*c*) The more strictly local origin of the breccias (to judge from their contained fragments) in the northern and central parts of the West-Somerset and Devon area.

(*d*) Between Watchet, Williton, and Porlock, the probability of large faults bringing together the Upper and Lower Marls; the high dip of certain sands locally flanking the Palæozoic rocks at their junction with the ever-present marls; the presence of beds at Alcombe and Minehead which might be referred to the conglomerate subdivision on lithological grounds and by position as far as ascertainable; the occurrence of beds bearing strong lithological affinities to the Lowest Triassic division, at Minehead and in the valleys between Dunster and Porlock, notably at Luckham; rendering the identification of beds subjacent to the conglomerate division very uncertain, and affording strong probability that the Keuper is alone represented, this area having been dry land during the deposition of the lower beds; and, owing to local causes, the basement beds of the Keuper in this locality betray a strong similarity to the basement breccias (presumably of Bunter age).

(*e*) The thickness of the Lower beds of the Trias (*i. e.* the series subjacent to the conglomerate division) seldom attains to 800 feet in the Burlescombe district, and in the neighbourhood of Wiveliscombe and Stogumber: in the districts embracing the valleys of Tiverton and Crediton it probably exceeds 1000 feet; but on the south coast a maximum development of 1650 feet might be conceded to it. From this it seems probable that a still greater development may have been attained in the area now occupied by the English Channel.

(*f*) The gradual replacement of the foreign quartzites of the Budleigh-Salterton pebble-beds by material capable of local derivation as the beds are traced northwards, indicates the existence of currents from the south during the early stages of the Keuper period.

My friend Mr. Linford, of Exeter, has devoted much time to the investigation of the origin of the Budleigh-Salterton quartzite-pebbles. After several visits to Normandy, he came to the conclusion that the pebbles were drifted by northerly currents and obtained from a previous extension of the quartzites of Calvados and La Manche* into the area now occupied by the English Channel (vide Rep. and Proc. of the Tamworth Nat.-Hist., Geol., and Antiq. Soc. vol. i. part 1, p. 41, &c.). Mr. Linford also visited Tamworth and Bromsgrove, in which localities he observed pebbles lithologically similar to the characteristic Budleigh pebbles (Comp. Brodie, Quart. Journ. Geol. Soc. vol. xxiii. p. 211, &c.) in drifts, and traced them to Triassic conglomerates in their respective vicinities.

Fifth proposition.—That, from the presence of numerous fragments of igneous rocks (quartz porphyries) in the basement beds of the South-Devon Trias, and from the absence of any known rocks in the county to which they could be readily referred, it appears probable that the cliffs and bed of the early Triassic sea were partly composed of igneous rocks of similar character to the foreign fragments. That any portions of such rocks left undestroyed would be likely to occur (1) under the Triassic beds in the vicinity of Dartmoor, (2) concealed by the Trias between Newton Abbot and Seaton, or (3) in the area now occupied by the English Channel.

The proof of this proposition is combined with its enunciation. My friend Mr. Vicary† has long been of opinion that the igneous fragments are directly referable to varieties of the Dartmoor granites, having visited many localities in Dartmoor where the granite is so similar in character to these porphyritic fragments‡ that nothing but a change in colour is wanting to complete the resemblance. Mr. Vicary succeeded in producing the change in colour by heating specimens of Dartmoor granite. Though there is no reason to suppose that the partially consolidated breccias in which the

* The Norman origin of the pebbles was first advocated by Mr. Salter, Quart. Journ. Geol. Soc. vol. xx. p. 287. Geol. Mag. vol. i. 1864, pp. 5, &c.

† Trans. Dev. Assoc. for 1867, vol. ii. p. 200.

‡ Decomposed flakes of mica are frequent in these fragments, quartz porphyries according to Prof. Judd. See a paper by Mr. T. Andrew, Trans. Dev. Assoc. for 1876.

fragments occur were subject to sufficient heat to produce the change in colour, yet such a change might have been produced by water percolating through ferruginous strata, or by similar chemical agencies. Though the occurrence of the fragments in the Trias within a certain distance of Dartmoor would favour this view, it is very problematical that the Dartmoor granite ever formed cliffs in the early Triassic sea; so I am inclined to refer the fragments to the sources mentioned in the proposition, but more especially to the last named, as a continuation of the Guernsey and Cape la Hogue granites may have furnished the material.

(*a*) If the granitic origin of the fragments be disputed, is it probable that the exposed portions of a granitic protrusion would exhibit the characters of a quartz porphyry? In that case, as no evidence of such offshoots from the Dartmoor granites is forthcoming in districts uncovered by Triassic rocks, I must agree with De la Beche* that these porphyritic fragments "may readily have formed portions of igneous masses covered up by the red-sandstone series;

"That the granite of Dartmoor may not have been covered by water when the red-sandstone series of the district was formed and the igneous rocks associated with it ejected"†.

The breccias frequently contain igneous fragments distinctly referable to the destruction of such igneous patches as those of Washfield, Killerton, Silverton, Spencecombe (north of Yeoford), &c. The outflow of these lavas seems generally to have accompanied or heralded the earliest deposition of Triassic sediments in the districts in which they occur; nor does it appear impossible that the eruption of quartz porphyries may have been in some way connected with their appearance.

(*b*) The porphyritic and Murchisonite fragments are confined to the South-Devon breccia, not extending further north than the northern boundary of the Crediton valley, and being limited to the eastward by a line drawn from Heavitree (Wonford quarries) to Exmouth.

(*c*) The general rounding of the porphyritic fragments, and the occasional occurrence of quartzites (which seem to me to resemble the Budleigh pebbles) in the breccia near the Labrador Inn, south of the Ness, Teignmouth, give colour to the hypothesis that these earlier Triassic sediments contained materials foreign to the present extent of the county, but perhaps represented beneath the bed of the English Channel.

Sixth proposition.—That on a comparison of the sequence of deposits in the midland counties with those of Devon and Somerset, from the evident continuity of the upper division, only, between the two areas, and from the absence of unconformity in the West-Somerset and Devon area, it is manifest—1st, that the Upper Marls, the Upper Sandstones, and probably the conglomerate and pebble-bed subdivision of Devon and Somerset are equivalent in time to the Keuper series of the midland counties; 2nd, that depo-

* 'Report on the Geology of Cornwall, Devon,' &c., p. 217.
† *Ibid.* p. 218.

sition took place in Devon and West Somerset between Keuper and Bunter times, bridging over the hiatus marked by unconformity in the midland counties.

This proposition can only be proved by a comparison with the results of Professor Hull's searching investigation into the constitution of the Triassic rocks of the midland counties.

Lest I should be thought to cast doubt upon his determinations, or in any way drag an already settled question into my individual branch of the subject, I must state that I am practically unacquainted with the Trias of the midland counties, and have not called in question the existence of the unconformity between Keuper and Bunter in that area which Professor Hull has so clearly demonstrated*. As far as the beds subjacent to the Keuper are concerned, my conclusions can in no way clash with those arrived at by Professor Hull in the midland counties. I have been compelled to make these remarks, as, from some undesigned coincidence to me unknown, Professor Hull was under the impression that the paper I have had the honour of submitting to the Society cast doubt upon conclusions he had established, or ignored results he had obtained.

Proof.—(*a*) As the Upper Marls of Somerset and Devon and the Upper Keuper Marl of the midland counties directly underlie the Rhætic beds, there can be no hesitation in regarding them as the same division.

(*b*) When we find beds of similar general character and thickness conformably underlying the Upper Keuper Marl in either area, even though from the existence of the Mendip-barrier ridge their sediments could not have commingled, we are forced on cumulative evidence to admit the probability of synchronous deposition.

This is the case with the Upper Keuper Sandstone of the midland counties and the Upper Sandstones of Devon and West Somerset. The general character of the Lower Keuper Sandstone is given by Professor Hull† as "Thinly laminated micaceous sandstones and marls passing downwards into white, brown, or reddish sandstone with a base of calcareous conglomerate or breccia." The Upper Sandstones of Devon and Somerset may be characterized as red sandstones and rock-sand‡, occasionally mottled with greenish spots, frequently containing calcareous nodules, buff and grey in places; almost a marlstone near Bishop's Lydeard, brecciated at about 50 feet from their base on the south coast. In particular instances modifications of this general character are noticeable. Near Wellington and Milverton, for instance, the sandstone passes downwards into a series of clays with intercalated beds of sand and occasionally of fine conglomerate near the base: this variety almost deserves the local epithet of waterstones; it is about 50 feet thick.

In some places between Milverton and Wellington the Upper Sandstones are with difficulty separable from the conglomerates, as

* Mem. Geol. Surv. "On the Triassic and Permian Rocks of the Midland Counties," pp. 31, 87, 94, 97.

† Mem. Geol. Surv. on Triassic &c. in Midland Counties, p. 10.

‡ Quart. Journ. Geol. Soc. vol. xxxii. p. 378.

the upper part of that subdivision is frequently represented by calcareous sandstones with so few contained fragments that the term conglomerate can only be truly applied to the beds to within from 30 to 50 feet of the base of the subdivision.

The same gradual change seems to have taken place in numerous places between Tallaton and Thorn St. Margaret's, as considerable difficulty is frequently experienced in fixing the upper boundary of the pebble-beds, owing to the downward passage of sand, through sand-beds in which pebbles are sparsely disseminated (false bedding is frequently indicated in their linear arrangement), to pebble-beds proper.

This difficulty has almost led me to regard the pebble-bed subdivision as an impersistent variation of the base of the Upper Sandstone; but the prevalence of faults renders such a conclusion far from certain. There can, however, be little doubt that the pebble-beds and conglomerates are old beaches which heralded the deposition of the Upper Sandstone, and were formed through a shoaling of the Triassic sea-bed, or through access to materials not before obtainable.

When we consider the isolation of the Triassic area of the midland counties from that of the south-western during the deposition of this upper-sand series, the absence of identical constitution is most natural; but the points of similarity are abnormally striking: compare, for instance, the following statements of Professor Hull with those which I have just given regarding the early part of the Upper-Sandstone period.

In the Peckforton-Hill district*, Cheshire, the Lower Keuper Sandstone is composed of:—

1. Waterstones	150 feet.
2. Hard red and white sandstones	200 „
3. A base of "hard calcareous breccia or conglomerate, full of current-bedding, and resting on a thin band of marl"	50 „

Kidderminster and Bridgenorth districts †: "The basement-beds of the Keuper in this, the typical district, consist of bands of marl and calcareous conglomerate passing into breccia."

Wolverhampton, near Penn and Oreton Hills: "The basement-beds of the Keuper consist of red marls and hard calcareous sandstone with pebbles."

South and east of Stourbridge ‡ the basement-beds of the Keuper "may be regarded as an old shingle beach."

"The introductory stage of the Keuper series was the formation of a second shingle beach, very largely developed in Shropshire and Worcestershire, but in a less-marked degree all over the central counties" §.

At Bull Hill ||, rock fragments, generally subangular and of small size, "pervade the beds from the base upwards for about 200 feet."

* Mem. Geol. Surv. on Triassic &c. of the Midland Counties, p. 77.
† *Ibid.* p. 70. ‡ *Ibid.* p. 69.
§ *Ibid.* p. 107. || *Ibid.* p. 69.

This remarkable similarity, coupled with the presence of quartzite fragments in the Keuper conglomerates of the midland counties, though by no means proving a continuity of the areas, shows that similar conditions prevailed synchronously and independently in early Keuper times in the midland and south-western counties.

Organic Remains.—Fossils have not been discovered in the Trias of either area under comparison below the Keuper Sandstones, whilst remains of the same genus have been found in the Upper* and Lower† Keuper Sandstones in each; for it is no stretch of imagination to regard the sandstone-beds of Claverham, near Yalton, of North Curry and Ruishton &c., as equivalent to the Upper Keuper Sandstone, bearing in mind the irregular mode of occurrence of that stratum‡.

As regards thickness, I have allowed a maximum of 1350 feet to the Upper Marls of the south coast of Devon§, but should be surprised to find the division exceed 1000 feet in Taunton Vale, the Bridgewater or Polden-Hill districts. It seems probable that Mr. Moore's‖ estimate of 2000 feet for the average thickness of the Trias outside the coal-basin embraces the whole formation in the Bridgewater district, if not meant to include the areas of Devon and West Somerset. At any rate the average thickness of 50 feet assigned to the Trias of the Mendip area, and the probability of its attenuation in Taunton Vale, would lead one to regard a thickness of from 700 to 800 feet a fair estimate for the Keuper Marls to the north of the Blackdown range, as they have not been fathomed at 609 feet in the boring at Compton Dundon¶.

Professor Hull** gives the following comparative thickness of the marl in the midland counties:—in Lancashire and Cheshire, 3000 feet; in Staffordshire, 800 feet; in Leicestershire, 700 feet.

He gives the following comparative thickness of Lower Keuper Sandstone:—in Lancashire and Cheshire, 450 feet; in Staffordshire, 200 feet; in Leicestershire and Warwickshire, 150 feet.

I have assigned 530 feet as the maximum thickness of the Upper Sandstones of Devon; but I am inclined to think that they seldom exceed from 400 to 450 feet, and may not attain to 200 feet in the Watchet valley or Bridgewater district.

It is very doubtful whether they extend far eastwards below the marls in the vale of Taunton, and rather probable that the area between the Mendip and Poldens was dry land during their deposition. If the pebble-bed and conglomerate subdivision be added, a total thickness of from 300 to 550 feet might be assigned to the Upper-Sandstone division in Devon and West Somerset.

(*c*) From the foregoing considerations I have no hesitation in

* Mem. Geol. Surv. on Triassic &c. pp. 5, 120; comp. Quart. Journ. Geol. Soc. vol. xxiii. p. 468.

† *Op. cit.* p. 120; comp. Quart. Journ. Geol. Soc. for May 1869, p. 152, &c., and vol. xxxii. p. 274.

‡ Mem. Geol. Surv. *op. cit.* p. 96.

§ Quart. Journ. Geol. Soc. vol. xxxii. p. 380.

‖ *Ibid.* vol. xxxii. p. 381.

¶ *Ibid.* vol. xxiii. p. 458.

** Mem. Geol. Sur. *op. cit.* p. 108.

correlating the Upper Marls and Sandstones of Devon with the Upper Keuper Marls and Lower Keuper Sandstones of the midland counties, each with each, and am very much inclined to consider the conglomerate subdivision as equivalent to the base of the Keuper in the midland counties.

(*d*) Beyond this it is impossible to correlate the beds in the two areas, either by lithological characters or position. For, whilst in the midland counties a distinct hiatus has been proved by Professor Hull in the frequent unconformities exhibited between the Keuper and Bunter (often amounting to the entire absence of the upper division of the latter and the unconformable overlap of the Keuper upon the Bunter Pebble-beds), in Devon we have a series of marls at least 500 feet thick on the south coast, conformably underlying the base of the Keuper*. From the Pebble-bed subdivision down to the base of the series, we have in Devon no evidence of unconformity or eroded surfaces.

Unfortunately the Lower Marls are cut off at Straight Point by a fault bringing up marly beds on sandstones. From this point to Exmouth, the constituents of the cliffs vary from marls in sandstones to beds of sandstone in marl, marl predominating toward Exmouth. These beds deserve the epithet of Waterstones, applied to them by Mr. Ormerod. The break in the sequence at Straight Point might be said to conceal an unconformity; but I have traced, between Thorn St. Margaret and Wiveliscombe, in very clear sections, a downward passage from Lower Marls, through an intercalated series of marls and clays with beds of sand, the latter predominating downwards, into the sandstones generally representing the basement beds in that neighbourhood.

The fault at Straight Point can scarcely have cut out less than 20 feet of the Lower Marls; so that the beds underlying the pebble-beds and overlying the basement sandstones and breccias can scarcely be less than 850 feet thick on the south coast, of which 500 feet are represented by pure marl without beds of sandstone underlying the Pebble-beds. The remainder may be regarded as a passage series into the lowest division. In their northerly extension these beds gradually attenuate; and they do not probably exceed 200 feet, taken together, to the north of Thorn St. Margaret.

(*e*) A fault occurs at Exmouth bringing up breccia against the Passage-marls. This, again, might be taken as a case of concealed unconformity, were it not for the presence, just north of Exmouth, of the beds cut out by the fault, and that they prove to be a series of sands passing upwards, as we have seen (locally), into Lower Marls, and passing downwards, generally by intercalation, into breccia, as may be seen between Dawlish and Langstone Point. In many places these sands represent the major part of the division; but near their old coast-line a beach-deposit of rubbly gravel seems

* Mr. Vicary has given a description of the relations of the Pebble-bed (Quart. Journ. Geol. Soc. vol. xx. p. 283, &c.). The conglomerate against which the marls are said to be faulted is a thin impersistent band of breccia in the Straight-Point sandstones, nowhere exceeding 10 feet in thickness.

to have been often contemporaneously formed (as near Collumpton and Tiverton, &c.).

(*f*) It now remains to consider the Basement-beds in their internal relations. On the south coast they are much disturbed by faults, which can seldom be laid down in inland localities, owing to the changeable nature of the division.

Taking the sands cut out at Exmouth as 100 feet in thickness, which, judging from their development between Honiton's Clist and Topsham, does not appear to be excessive, we might regard the beds represented between Langstone Point and Dawlish* as a passage-series into breccia. For this passage-series, which appears to terminate at the mouth of the tunnel at Dawlish (though repeated in several places towards the Clerk Rock by faults), 150 feet cannot be regarded as an excessive thickness. The subjacent breccia is much faulted, but appears to belong to the same horizon in the division, from its outcrop to Watcombe, where the breccio-conglomerates with limestone pebbles crop out on the top of the cliffs. It may be regarded, with due allowance for repetition by faults, as at least 500 feet in thickness, as the cliffs composed of it sometimes exceed 350 feet in height.

The limestone conglomerate of Watcombe may be regarded as affording a further thickness of 400 feet; and the local series of basement clays and sands of Petitor and Watcombe may be taken as 100 feet.

If the Paignton beds are of earlier date, an addition of from 150 to 200 feet would have to be made; but I regard them as the equivalents of the basement-beds to the north of Babbicombe, and their difference in character as due to local sources of derivation.

(*g*) Upon the foregoing determination the mean and maximum thicknesses of the South-Devon basement-beds, divided into three horizons, each passing into the other by intercalation, would be as follows:—

	Mean. feet.		Maximum. feet.
1. Sandstones and passage-sands and breccias ...	250	to	400
2. Rubbly breccia with igneous boulders	500	,,	600
3. Conglomerate and breccia with numerous limestone fragments	400	,,	500
4. Watcombe and Petitor sands and clays	100	,,	150
Total thickness.........from	1250	to	1650

When traced inland we find a very great attenuation of this division, and that the variability of its constituents precludes the settlement of any definite general horizons. Thus, north of Exeter, the whole superficial portion of the division is represented by sands and sandstones (fissile near Broad Clist) with occasional clayey beds; yet, from the subjacent position of the breccia of the Crediton valley, it

* The Langstone-Point and Exmouth breccias are regarded as portions of the subjacent series thrust up by faults.

is probable that similar beds may be concealed by the sands, so that an approximate thickness cannot be arrived at.

Northwards from the Crediton valley the lowest division is generally represented by sands with local intercalations of, and possibly replacement in their upper beds by, clay, on the low grounds; whilst the Palæozoic boundary is flanked by Triassic gravels of local materials resting on considerable heights (exceeding 900 feet above the sea at Cadbury Camp, north of Thorverton) on the west side of the Culm valley, between Silverton and Tiverton, and well developed on the flanks and near the western extremity of the Tiverton valley. This gravel appears to have originally exhibited the same relations to the sands and clays of the division, that exists between the Dolomitic conglomerates and marls of the Mendip area; for it is never visible at considerable distances from the exposed palæozoic rocks.

As this Triassic gravel rests on slopes of some hundred feet in vertical extent, we may regard the basement-beds whose shoreward margin it represents as about 600 feet in thickness.

In the Tiverton valley the sands of the lowest division seem to give place to breccio-conglomerate near Sampford Peverell; this approaches in character, sometimes to the hard beds of the south-coast breccia, sometimes to the Keuper conglomerates of Thorn St. Margaret's and Wiveliscombe. On following this division northwards, we find a considerable attenuation, real or apparent, between Sampford Peverell and Wiveliscombe: toward the latter place the top of the division consists of breccio-conglomerate, seldom exceeding 50 feet in thickness, the lower beds being represented by sands.

In the Watchet valley breccia forms by far the larger portion of the whole division, and the sands are intercalated with it.

In the neighbourhood of Stogumber the basement-beds may exceed 500 feet.

(*h*) I am inclined to think that this division is not represented by contemporaneous deposits in the Bridgewater area; if so, they are of a very different character: nor can I say if the Lower Marls are represented by equivalent deposits on the north-east of the Quantocks.

(*i*) It would be worse than idle to attempt a correlation of the variable basement-beds of the Devon and West-Somerset Trias with the Bunter divisions of the midland counties. There are occasional points worthy of comparison between them, as the degeneracy of the Bunter pebble-beds into a loose gravel in places*; but even if coincidences were marked and numerous, the different conditions experienced by each area would preclude the derivation of reliable results from them.

(*j*) Taking the division as a whole, however, we may compare the following comparative thickness of the Bunter in the midland counties with our lowest division with advantage.

Thickness of Bunter.—In Lancashire and W. Cheshire, 1200 to 1750 feet; in Staffordshire, 150 to 600 feet; in Leicestershire and

* Mem. Geol. Sur. on Triassic &c. of Midland Counties, p. 59.

Warwickshire, 0 to 100 feet. Comparing these with the lowest division of the Devon and West-Somerset Trias, ranging probably from 200 to 1650 feet in thickness, there is fair ground for inferring that it represents the Bunter.

(*k*) If this be so, it is surely not improbable that the intervening marls and their subjacent passage-beds, representing a thickness varying from 200 to 850 feet, are equivalent to the Muschelkalk of Germany and the "Calcaire coquillien" of France, the difference in character being due to an uninterrupted continuance in Devon and West Somerset of those unfavourable conditions to organic existence which prevailed during the deposition of the Keuper and Bunter sediments.

Discussion.

The President called attention to the asserted existence of land in the Devon area, and stated that the investigation which he had once made of the Magnesian Limestone in the north led him to the belief that land must have existed there.

Mr. Whitaker pointed out that the author had found that in the Devon area the beds thin northward, while Prof. Hull had shown that the beds of the northern area thin to the S.E. He called attention to the discovery of rock like New Red Sandstone in one of the deep borings near London.

Prof. Ramsay remarked upon the want of illustrative sections, but said that he agreed with Mr. Ussher as to the existence of a barrier near the Bristol Channel, but thought that the strata were in no true sense of the word marine. He also approved of the idea of a gradual overlapping of the Triassic strata, as on the Mendips the upper strata of the Trias were found, the Bunter beds being absent.

Mr. Johnston-Lavis said that, with regard to the absence of diagram-sections, it was extremely difficult in that district to trace for any distance continuously any subdivision. He thought that on the lake-theory it would be impossible to correlate beds, since they might differ entirely in their lithological composition, although deposited contemporaneously in different areas and in very variable thicknesses.

Mr. Etheridge said that he had been able to ascertain from specimens in the Penzance Museum that the Budleigh-Salterton pebbles came from Gorran Haven on the southern coast of Cornwall. Similar fossils occur near Torquay and in Staffordshire. *Orthis redux* was common among the specimens at Penzance; and *Lingula crumena* and several Trilobites also showed that some of the pebbles were derived from Llandovery rocks. These rocks also occurred at Gorran Haven. The Penzance museum also contains fossils singularly like those from the Eifel.

Mr. Whitaker stated that he had himself, on lithological grounds, suggested the Gorran-Haven region as a source for the Budleigh-Salterton pebbles.

Prof. Hughes remarked that, as a rule, strata were thickest near the land, whilst the author in his paper spoke of thickening to the south, and of land to the north. Hence it would appear that most of the material forming these deposits must have come from France; and he thought that Mr. Davidson had identified some of the Budleigh-Salterton Brachiopods with French species.

Prof. Bonney said that the case supposed by Mr. Ussher seemed to him the same that occurred in the Staffordshire area, north of the Silurian barrier. He doubted whether Triassic beds were likely to be found under London.

31. *On the so-called* "Greenstones" *of* Central *and* Eastern Cornwall. By J. Arthur Phillips, Esq., F.G.S. (Read April 3, 1878.)

[Plates XX.–XXII.]

On a former occasion I had the honour of laying before this Society the results of a series of microscopical and chemical examinations of the principal "Greenstones" of the western districts of Cornwall *. In the present paper it is my intention to describe the cognate rocks of the central and eastern portions of that county, commencing near the point where I then left off, and gradually proceeding eastward.

Central Southern District.—A mile west of St. Austell, and a quarter of a mile north of the turnpike-road leading from that town to Truro, is a quarry from which stone has long been obtained for road-making. This quarry, which adjoins the Sanctuary fields belonging to the glebe of the parish of St. Mewan, yields a hard blackish-green rock, traversed by numerous cross joints, of which the surfaces are covered by an unctuous brownish-red material, containing a large proportion of hydrated ferric oxide.

The band furnishing this stone courses in an easterly direction from the farm of Quoit to the quarry above mentioned, and is shown on the Geological Map as extending thence in a south-easterly direction to the sea-cliff near Duporth. Its width in the Sanctuary quarry is about thirty yards; near the centre of the band the rock is distinctly crystalline, but becomes gradually less so on either side, until finally, assuming a slaty structure, it merges into the enclosing killas.

This rock was analyzed and microscopically examined by the author in the year 1870 (Phil. Mag. xli. p. 97, 1871), at which time the portion of the band laid open was much fissured, and had been subjected to such extensive alteration that it was difficult to obtain fresh representative specimens. Thin sections, however, were found to consist of much-altered felspar (a portion of which was triclinic), hornblendic belonites, viridite, numerous large crystals of magnetite (many of which were partially converted into hydrated peroxide of iron), and hexagonal prisms of apatite—the whole being more or less obscured by a flocculent greenish-grey product of alteration.

On a more recent visit to this quarry (January 1877), it was found that the rock which was then being raised was not only more decidedly crystalline, but also considerably fresher than that examined seven years previously, and then supposed to be an altered diorite. It likewise closely resembled some varieties of dolerite from the neighbourhood of Penzance; and a new series of sections was consequently prepared, and an analysis made of the rock in its less-modified state.

* "On the so-called 'Greenstones' of Western Cornwall," by J. Arthur Phillips (Quart. Journ. Geol. Soc. vol. xxxii. pp. 155–178).

This stone is generally somewhat fine-grained, very dark in colour, and without visible crystals of felspar; in places, however, near the centre of the mass, there are patches of a lighter colour, in which distinct felspar crystals, 3 millims. in length, can be distinguished.

For the purposes of analysis fragments of the darker and more close-grained rock were selected, since the lighter-coloured variety containing visible felspar can only be regarded as of exceptional occurrence. An analysis, in duplicate, afforded the following results (sp. gr. =2·97):—

	I.	II.
Water { hygrometric	·27	·30
Water { combined	·71	·67
Silica	50·42	50·41
Phosphoric anhydride	·74	·83
Alumina	19·10	18·91
Ferric oxide	2·50	2·44
„ persulphide (FeS_2)	·43	·42
Ferrous oxide	11·03	11·11
Manganous oxide	·40	·42
Lime	5·81	5·90
Magnesia	1·80	1·72
Potassa	1·67	1·60
Soda	5·13	5·22
Lithia	·13	·11
	100·14	100·06

The above analysis does not materially differ from those of the augitic rocks from the neighbourhood of Penzance, the chief points of variation being that there is slightly more silica and decidedly less lime and magnesia than is present in the rocks on the shores of Mount's Bay.

The principal difference between the above results and those obtained by the analysis of more highly altered specimens from the same locality, consists chiefly in the presence of a slightly larger amount of silica and lime, together with an appreciable amount of magnesia, while the percentage of ferric oxide is considerably less. Microscopical examination shows that the larger proportion of lime and magnesia is accounted for by the fact of the fresher rock containing both unaltered augite and numerous hornblendic pseudomorphs after that mineral. The larger quantity of ferric oxide contained in the rock analyzed in 1870, as compared with that found in specimens more recently examined, is explained by the presence in the former of numerous large and partially peroxidized crystals of magnetite, while in the latter that mineral is more sparingly disseminated, and is in an unaltered state. Lithia was not sought for in the earlier analysis; and consequently, if present, this body was estimated with the other alkalies.

Thin sections of the dark close-grained rock of which an analysis is given above, when examined under the microscope, are seen to be composed of reticulated felspar crystals, of which the majority are triclinic, although monoclinic felspar is also present. Many of the crystals of felspar are about 1·5 millim. in length, and are not unfrequently more or less curved. With the felspar are associated crystals and crystalline patches of augite, as well as numerous pseudomorphs after that mineral: the latter are usually composed of felted hornblendic belonites; but viridite in small quantity is also present. The augitic crystals are generally converted near their edges into feathery hornblende; and their structure is sometimes partially destroyed by patches of viridite. This rock likewise contains numerous hexagonal prisms of apatite, and small crystals of magnetite which are apparently unaltered; no grains of quartz, such as are occasionally met with in specimens from the shores of Mount's Bay, were observed in any of the six sections of this rock which were examined. A small quantity of the bright blue mineral (indicolite), mentioned in a former paper as occurring in the rock from Terrace Quarry, was found in one of the sections.

The comparatively coarse-grained variety, in which felspar is readily distinguished by the naked eye, is seen under the microscope to be composed largely of but slightly altered crystals of plagioclase, although monoclinic felspar is also present. From lithia having been found in this rock it is probable that some portion of the monoclinic mineral may be spodumene *.

No unaltered augitic mineral was detected in any of the sections of this variety of rock, although hornblendic pseudomorphs after that mineral are numerous; in other respects the coarsely crystalline rock resembles the fine-grained variety.

The foregoing examination of thin sections of this rock conclusively shows that it is not an altered diorite, as was formerly supposed, but that, on the contrary, it is a modified dolerite of the class abundantly occurring in the neighbourhood of Penzance.

A quarry which was opened many years since on a somewhat similar band at Blowing-House Hill, immediately west of the town of St. Austell, is now full of accumulated rubbish; but if fresh specimens of rock were obtainable from this locality, it would probably be found nearly similar in composition to that above described.

At Duporth, two miles east of St. Austell, is an outcrop of eruptive rock in the sea-cliff bounding the property of Mr. G. Freeth. This rock, which consists of a greyish matrix enclosing numerous angular white spots, is soft, and somewhat unctuous to the touch, while the general appearance of the mass is that of an aggregation of more or less rounded boulders cemented together by a mixture of an asbestus-like mineral and hydrated ferric oxide.

On closer examination it becomes evident that this peculiar structure of the mass is due to the circumstance that the rock, which is highly magnesian, has undergone decomposition along

* When it is remembered that the atomic weight of lithium is only 7, while that of potassium is 39·1, it becomes evident that the amount of lithia found is of more importance than would at first sight appear. Traces of lithia were found in various rocks of this class in which its amount was not estimated.

certain lines of fissure, and that the result has been the production of the minerals forming the cement now holding together the various isolated blocks.

An analysis made on a freshly broken fragment of this rock afforded the following results (sp. gr. =2·80):—

Water { hygrometric	·72
Water { combined	9·29
Silica	35·74
Phosphoric anhydride	·18
Alumina	12·23
Ferric oxide	4·68
Ferrous oxide	13·84
Manganous oxide	·98
Lime	trace
Magnesia	22·13
Potassa	trace
Soda	·25
	100·04

The white spots described as being enclosed in the grey matrix are, in the aggregate, considerably in excess of the base, and are usually about 3 millims. in length, evidently representing altered crystals of felspar. Thin sections examined under the microscope are observed to consist largely of a granular colourless material resulting from the alteration of felspar, through which are disseminated a few yellowish brown microlites and slightly altered grains of magnetite, together with patches of a cryptocrystalline green mineral. A few needles of apatite are also present.

It will be observed that, both in appearance and in chemical composition, this rock differs essentially from the altered dolerites of the class found at the Sanctuaries and elsewhere; in its general structure and mineralogical composition it also differs materially from those rocks*.

* At the meeting of the British Association held at Plymouth in 1877, a communication was read by Mr. J. H. Collins, entitled "On the Serpentine of Duporth, in St.-Austell Bay, Cornwall."

In this paper he gives the following as the composition of a specimen of this rock:—

Water	8·65 (of this 2·73 was lost below 120° C.).
Silica	37·09
Titanic acid	trace
Phosphoric acid	·21
Alumina	19·90
Ferric oxide	15·54
Ferrous oxide	2·02
Oxide of manganese	trace
Lime	trace
Magnesia	15·90
Alkalies	trace
	99·31

It will be observed that the results of the two analyses differ considerably in the

Near Tregorrick, a little east of the Pentewan valley, a quarry is worked upon a "blue elvan," very closely resembling that raised near the Sanctuary fields, but usually somewhat less hard and often more slaty in its structure. Under the microscope it is observed to have undergone extensive alteration; triclinic felspar is still, however, distinguishable, and patches and microlites of hornblende are abundant; but augite has entirely disappeared. There is a little, probably dissociated, silica present in the form of quartz granules; apatite is observed in considerable quantities; and pseudomorphs after magnetite or ilmenite are abundant *; crystalline chlorite sometimes occurs in the partially kaolinized felspar.

On the sea-coast at Hallane Mill, near the Blackhead, there is another outcrop of a rock of nearly similar character; but it has in some respects undergone less extensive metamorphism, since it still retains a considerable amount of an unaltered augitic mineral. Sections obtained from this locality mainly consist of augite, hornblende, a very subordinate amount of plagioclase, a little kaolinized felspar, and peroxidized and hydrated magnetite, apatite, and quartz; the latter encloses well-defined crystals of chlorite, and occasionally contains minute liquid-cavities.

A quarter of a mile east of this point the doleritic rock is intersected by what at first sight appears to be an elvan dyke. A microscopical examination, however, of thin sections shows that this apparent dyke is a vein chiefly consisting of yellowish quartz containing fragments of the enclosing rock and patches of pyrites, together with a few crystals of mispickel.

East of this point the igneous rocks of the Blackhead proper are for the most part much altered. They contain a considerable amount of quartz, crystals of triclinic felspar (many of which have become partially obliterated and merged into an amorphous mass), a large amount of magnetite, a few long needles of apatite, and interlaced nearly colourless hornblendic microlites. The "greenstones," of which a considerable portion of this promontory is composed, have not been observed to contain any unaltered pyroxenic mineral; there can nevertheless be little doubt that, like those of the Sanctuaries,

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amounts of alumina and magnesia, and in the relative proportions of ferric and ferrous oxide found.

An examination of a specimen operated upon by Mr. Collins shows that it has undergone a change, differing somewhat in character from that previously analyzed in my laboratory, as it is not only harder and darker in colour, but also encloses a considerably less proportion of what would appear to be altered crystals of felspar.

* When the black crystalline grains which occur in rocks belonging to this class become transformed by alteration into an opaque greyish-white substance, the mineral is generally mentioned by petrographers as *ilmenite*. Many of the crystals so altered in Cornish rocks would appear to belong rather to the first than to the third crystalline system; but their outlines in thin sections are so dependent upon the direction of the plane in which they have been cut through, that their identification is often difficult. There is also reason to believe that a large proportion of the magnetite in such rocks is titaniferous.

Tregorrick, and Hallane, they were originally augitic rocks which have been subjected to alteration.

Slaty Agglomerates.—In addition to the doleritic rocks above described, which, under the name of "blue elvans," are largely employed as road-material, there are others in this neighbourhood which, although known by the same name and employed for similar purposes, are manifestly of sedimentary origin.

A rock of this description which is quarried at Tregian, in the parish of St. Ewe, is of a dark grey colour, distinctly lamellar in structure, and not unfrequently encloses flakes of a dark blue clay-slate. Under the microscope it is seen to be mainly composed of slightly rounded grains of quartz, with fragments of felspar joined by a transparent cement, through which microlitic viridite is disseminated; it also occasionally encloses iron pyrites and minute flakes of silvery-white mica. A very considerable proportion of the felspar, but not quite the whole of it, is plagioclase.

Similar to the above is a rock worked for road-metal at Dairy, in the same parish. The stone quarried in this locality, however, is darker in colour, contains a larger number of fragments of blue killas, and is more distinctly fissile than that found at Tregian. Sections examined under the microscope are seen to be largely composed of quartz granules, of which the outlines are generally not perceptibly rounded, together with grains of felspar and fragments of hornblende, the whole being united by a transparent cement enclosing a little white mica with grains of partially hydrated magnetite. This ground-mass is traversed by numerous feathery microlites.

A rock somewhat resembling this, although of a dull brown colour, and which might perhaps be more correctly classed as a sandstone, is quarried near the "Rock House" at Pentewan. This is largely composed of quartz granules, consolidated by a cement containing flakes of white mica, and a few patches of viridite, the whole being more or less coloured by hydrated ferric oxide.

Central Northern District.—The next extensive "greenstone" region lies on the northern coast of the county, reaching from Trevose Head on the west, to beyond Camelford on the east, and extending in a southerly direction a little beyond the parish church of Egloshayle.

Near the coast-line these rocks occur in nearly parallel bands, of which the direction approaches closely to east and west; but in the vicinity of the granitic area, of which Brown Willy is the culminating point, they approximately coincide with the lines of its general contour. Ash-beds also occur along the northern coast.

The rocks in this district, marked in the Survey-Map as "greenstones," belong to at least three distinct classes—namely, crystalline pyroxenic rocks, vesicular lavas, and foliated ash-beds.

In the neighbourhood of Wadebridge the igneous rocks belong to the first of these classes, and closely resemble the altered dolerites of Penzance and St. Austell. In some cases the pyroxenic constituent remains partially unaltered, while in others it has not only been completely transformed into either viridite or feathery or belonitic hornblende, but the felspar has also to a great extent become decomposed into an amorphous or somewhat granular mass.

Numerous bands of augitic and other crystalline rocks occur in the strike of the schistose beds, extending eastward from Pentire Point through Endellyon to Port Isaac. Some of these belong to the doleritic class; while others are vesicular and lighter in colour, the vesicles being for the most part filled by a mixture of calcite with viridite or chlorite, or of quartz and chlorite. The dark-coloured pyroxenic bands appear to be frequently intrusive, and to break through the slates in such a way as to indicate that the latter must have been solidified before the intrusion of the igneous rock. The vesicular rock, sometimes called "dunstone," presents, on the contrary, all the characteristics of a lava which has flowed over the surface contemporaneously with the deposition of the accompanying sedimentary beds *.

"*Blue Elvans.*"—A dark-green trap, which at Pentire Point is interbedded with the vesicular lavas, presents several bold outcrops; but since it has not been opened upon by quarrying, it is impossible to obtain perfectly fresh specimens by merely breaking as far as possible into the mass with the hammer. Fragments thus procured are distinctly crystalline, but show by their dull colour that they have, to a certain extent, suffered from weathering.

The presence of carbonic anhydride and of a large amount of combined water in this rock, as shown by the following analysis, likewise indicates that it has undergone a considerable amount of alteration (sp. gr. =2·88):—

Water { hygrometric	·45
Water { combined	4·71
Silica	38·53
Carbonic anhydride	3·21
Phosphoric ,,	·37
Sulphuric ,,	trace
Alumina	15·41
Ferric oxide	2·66
Ferrous oxide	13·66
Lime	8·95
Magnesia	8·66
Potassa	·47
Soda	2·61
	99·69

The felspar in this rock is not abundant; but a certain proportion

* The late Sir Henry T. de la Beche, whose views with regard to the geology of igneous rocks were far in advance of those of the majority of his contemporaries, explains the occurrence of these rocks on the northern coast of Cornwall in a similar way ('Geology of Cornwall, Devon, and West Somerset,' p. 88).

of it is easily recognized as plagioclase; hornblende occurs plentifully in the form of interlaced microlites; and the ilmenite is much altered. It contains calcite and patches of an unaltered pyroxenic mineral; but none of the sections examined were observed to contain apatite.

In the parish of St. Minver there is a comparatively coarse-grained crystalline rock of a general dark green colour, containing occasional crystals of felspar. The felspar has in some instances so merged into a semitransparent ground-mass, that when examined by polarized light no distinct crystalline outlines are apparent; numerous crystals of a triclinic felspar, however, are sometimes present. Crystals of apatite are also of frequent occurrence; but the ilmenite has become to a large extent replaced by a mineral of a greyish-white colour. In some specimens augite is plentiful; but it has often become so changed around the edges of the crystals that, if the alteration were continued, they would become converted into uralite.

Fig. 5, Plate XXII., represents a section of this rock, magnified 14 diameters, exhibiting the gradual alteration of augite.

At Slade's Bridge, three quarters of a mile east of the parish church of Egloshayle, a greenish grey coarse-grained trap is extensively worked for road-metal; this band is of considerable thickness, and appears to be interbedded with the associated slates. An analysis of this rock afforded the following results (sp. gr. =2·78):—

Water	hygrometric	·40
	combined	4·96
Silica		46·65
Carbonic anhydride		1·90
Phosphoric ,,		trace
Alumina		19·36
Ferric oxide		2·61
Ferrous oxide		9·55
Lime		4·08
Magnesia		5·34
Potassa		·32
Soda		4·54
		99·71

The presence of carbonic anhydride, together with that of a considerable percentage of combined water, indicates that this rock has undergone a certain amount of decomposition.

Under the microscope it is seen to consist of a mixture of triclinic felspar which is often partially kaolinized, with viridite and a little hornblende. It likewise contains patches of ilmenite, which have to a considerable extent been replaced by an opaque greyish material; a few grains of quartz, and perhaps some small crystals of epidote, are also present. No unaltered augite was observed in this rock.

A quarry has been opened on a band of crystalline rock of a green colour, at Tregellan, in the parish of St. Mabyn. This contains no augite, but a considerable amount of hornblende and viridite, together with flakes of dark brown mica, apatite, and crystalline patches of partially replaced magnetite or ilmenite. A few minute crystals of a yellowish mineral, which is probably epidote, are also present; these are often arranged around fragments of ilmenite or magnetite as a centre. A large proportion of the felspar is triclinic; but in some places it is so far decomposed as to merge into an almost amorphous mass.

At Trebisquite, in the same parish, a slaty rock occurs which has evidently undergone a large amount of alteration. When sections from this locality are examined, they are found to consist of a colourless transparent base, enclosing patches of viridite, through which are disseminated reticulated microlites of a greenish colour. A large amount of much-altered ilmenite is also present; but no well-defined crystals of apatite could be distinguished. If felspar was an original constituent of this rock, it has become completely metamorphosed.

Near Highgate, St. Mabyn, there occurs a band of nearly similar rock. This is even more slaty than the foregoing, and has suffered still more extensively from alteration. A microscopical examination of thin sections from this place shows that the rock is composed of a granular transparent ground-mass, in places stained by hydrated ferric oxide, and that it encloses numerous granules of quartz with a few indistinct greenish microlites, together with a little altered magnetite. This rock appears to have been originally vesicular, the cavities being now filled either with calcite or with a mixture of that mineral with granular quartz and viridite.

Half a mile east of the parish church of St. Tudy a quarry has been opened in a wood immediately above Penrose Cottage, on the Wadebridge road, where a bluish-grey trap is somewhat extensively worked as a material for road-making. Although of eruptive origin, this rock is distinctly foliated. An examination of thin sections shows it to consist of a ground-mass mainly composed of plagioclase, viridite, and green hornblende, through which are disseminated numerous minute garnets, a considerable amount of titanoferrite, a little apatite, and occasional grains of quartz.

A much-altered doleritic rock is quarried near Michaelstow Beacon; and a band of greenish-blue slate has been worked for road-material at Helsbury, a little east of the Camelford road. This slate has a ground-mass largely consisting of granular quartz, enclosing a few minute flakes of brown mica, with a nebulous grey mineral and occasional greenish belonites; it also encloses grains of iron pyrites.

A hundred yards west of the main street at Camelford a hard cherty grey rock is worked for road-metal at a point known as "Hill Head." A freshly broken specimen from this locality afforded by analysis the following results (sp. gr. $=2{\cdot}92$):—

Water { hygrometric	·55
Water { combined	1·14
Silica	49·66
Phosphoric anhydride	·25
Alumina	20·85
Ferric oxide	2·07
„ persulphide	trace
Ferrous oxide	4·99
Manganous oxide	trace
Lime	14·19
Magnesia	2·77
Potassa	1·44
Soda	2·05
	99·96

Thin sections of this rock are seen to consist of a granular transparent nearly colourless ground-mass, containing quartz, in which are enclosed numerous imperfect yellowish crystals, which seldom exceed 0·5 millim. in diameter, and are often disposed in irregular bands; these alternate with stripes of a mineral resembling sericite.

The guttate bodies exhibiting these rounded outlines, and which are not unlike distorted globules of gum-arabic, are probably to a large extent imperfectly crystallized garnets, although they sometimes afford colours in polarized light. These minute crystals, however, are intimately mixed with the double-refracting ground-mass, portions of which have often become enclosed in them; and it is consequently difficult to determine to what extent the colours referred to may be due to this circumstance. In chemical composition this rock does not materially differ from the altered dolerites.

About three quarters of a mile from this point, on a farm called Trenewth, a little north-east of the town of Camelford, is a hackly bluish-green slaty rock, traversed by numerous thin veins of milky quartz. A specimen of this rock, which is quarried, under the name of "blue elvan," as a road-material, when subjected to analysis, afforded the following results (sp. gr. =2·97):—

Water { hygrometric	·30
Water { combined	·60
Silica	48·23
Phosphoric anhydride	·37
Alumina	19·35
Ferric oxide	3·57
„ persulphide	trace
Ferrous oxide	8·38
Manganous oxide	trace
Lime	8·04
Magnesia	4·14
Potassa	1·21
Soda	5·84
	100·03

Sections of this rock were found to consist of a transparent base, enclosing numerous angular fragments of quartz and grains of unaltered magnetite, together with occasional specks of iron pyrites; throughout this mixture are thickly disseminated groups of needles of green hornblende, arranged in nearly parallel bands. This very closely resembles some of the slaty hornblendic rocks of the St.-Ives and Cape-Cornwall districts, and is overlain by a stratum presenting the appearance of an imperfectly consolidated ash-bed.

Fig. 1 (Plate XX.) represents a section of this rock magnified 22 diameters.

In a field near Hendra Chapel, on the left of the Launceston road, three and a half miles east of Camelford, a quarry is worked upon a rock of a sage-green colour, enclosing lamellar patches of a mineral possessing a lustre somewhat approaching that of bastite.

A freshly broken specimen from this locality afforded the following results (sp. gr. =2·94):—

Water	hygrometric	·24
	combined	2·64
Silica		44·69
Alumina		17·58
Ferric oxide		4·52
Ferrous oxide		7·10
Manganous oxide		trace
Lime		10·54
Magnesia		9·81
Potassa		trace
Soda		2·87
		99·99

When thin sections are examined under the microscope, the lamellar striated mineral before referred to is found to be distinctly dichroic, and to present other characteristics of hornblende. A triclinic felspar is also present, as well as a considerable amount of an imperfectly crystallized colourless transparent mineral, which I was unable to identify, but which Professor Zirkel believes to be augite *. With these are associated viridite, numerous crystalline patches of altered ilmenite, and a few granules of quartz.

Near the church of St. Clether a high bluff runs for some distance parallel with the valley, and is composed of a slightly modified dolerite, in which all the constituents frequently occur in

* Professor Zirkel, who has kindly examined a thin section of this rock, is of opinion that the nearly colourless imperfectly crystallized mineral does not exhibit sufficiently characteristic peculiarities to admit of its absolute identification; but he believes it to be probably a variety of augite, especially as pale sahlite is of frequent occurrence in crystalline hornblendic rocks, as well as in hornblendic and chloritic slates. He further remarks that its cleavage and optical properties are not contradictory of this hypothesis.

an unaltered state. This rock is associated with various bands of slate or shale, which are probably consolidated doleritic ash-beds.

"*Dunstones.*"—By this name the ancient lavas of Northern Cornwall are locally distinguished. These, when freshly broken, are greenish-grey in colour, and have a finely amygdaloidal structure. They sometimes occur in amorphous masses of considerable depth, divided into blocks by joints crossing one another at various angles; but in other cases they form distinctly foliated sheets of varying thickness.

The latter variety of conformation is apparently often due to a former state of fluidity, while in other instances the rocks exhibiting this peculiarity may have been deposited in the form of ash. The slaty structure of such rocks may also, in some cases, have been produced by the operation of influences by which the lamination of the associated sedimentary beds has been effected. By weathering, ferrous oxide becomes peroxidized and hydrated, imparting a dark-brown colour to the mass, which becomes spongy from the removal of the calcite, with which a large proportion of the vesicles are filled.

Two specimens of lava from this district afforded the following results by analysis:—

	I.	II.
Water { hygrometric	·51	·56
Water { combined	3·98	4·30
Silica	43·23	40·05
Carbonic anhydride	2·61	3·67
Phosphoric ,,	·97	·63
Alumina	21·37	20·46
Ferric oxide	1·69	1·83
,, persulphide	·33	trace
Ferrous oxide	9·53	12·66
Manganous oxide	trace	trace
Lime	6·66	6·62
Magnesia	3·57	4·28
Potassa	trace	trace
Soda	5·63	4·82
	100·08	99·88
Specific gravity	2·82	2·83

These lavas, from their greater porosity, have undergone a larger amount of alteration than the more compact doleritic rocks; and it consequently becomes impossible to institute a strict comparison between their original compositions. If, however, the lime be regarded as having formed an integral part of the unaltered rock, and allowance be made for the presence of carbonic anhydride as well as for the increased proportion of combined water present in these lavas, their chemical composition will not be found to differ very materially from that of the crystalline dolerites. It is to be remarked, however, that in the case of these lavas potash occurs in the form of traces only.

I. This is a greenish amygdaloidal lava from Pentire Point, in which the cavities are usually of the size of hemp-seed, and are considerably elongated in the direction of its line of flow. Sections examined under the microscope are seen to be largely composed of plagioclase, with occasionally traces of unaltered augite, together with viridite and chlorite, as well as a slightly dichroic mineral, which is perhaps hornblendic, resulting, like the chlorite and viridite, from the alteration of augite; they also contain slender crystals of apatite, pseudomorphs after ilmenite, and a considerable amount of the greyish dust-like mineral often present in altered crystalline rocks. This latter substance, which by transmitted light has a dark grey tint, when examined as an opaque object appears either of a light grey hue or perfectly white.

The cavities in this lava have generally been filled either with crystalline calcite, with a mixture of calcite and viridite, with quartz and chlorite, or with matted greenish microlites, which are often distinctly dichroic. Viridite occasionally first lined a considerable portion of the interior of a vacuity, after which the filling-up was continued with crystalline calcite. A material of a dark green colour, which sometimes covered the interior of the vesicle previous to the deposit of viridite, is perhaps due to the decomposition of a volcanic glass.

A cavity in this rock, filled with crystalline quartz and vermicular chlorite, is represented (magnified 30 diameters) in fig. 2 (Plate XX.). This quartz encloses numerous very minute and somewhat rounded cavities, which are generally empty; and in no case was a movable bubble observed in those contained in any of the sections of this rock. In some few cases the cavities have become filled with a mixture of quartz, viridite, and granular pyrites.

II. This specimen was obtained from a quarry on the left of the main road entering the village of Port Isaac from the south, and differs but little from the foregoing, excepting that it is somewhat coarser in texture and rather more schistose in character.

On a farm called Trevarthan, three and a half miles south-east of Port Isaac, a quarry is worked upon a bed of lava of considerable thickness; the rock, however, is so decomposed that the crystals of felspar have frequently become partially obliterated.

At Bokelly, in the parish of St. Kew, and in various other localities in this district, greenish foliated rocks, presenting, in hand-specimens, the appearance of indurated ash-beds, have been opened upon for road-making materials. Their colour is identical with that of the before-described lavas; and the vesicles which they contain, although small, are very numerous. Crystals of felspar, which have occasionally the transparency of sanidine, are sometimes enclosed in this rock, a specimen of which, from Bokelly, afforded on being analyzed, the following results (sp. gr. =2·82):—

Water { hygrometric	·38
Water { combined	3·93
Silica	36·74
Carbonic anhydride	9·10
Phosphoric ,,	·35
Alumina	17·55
Ferric oxide	1·62
Ferrous oxide	8·23
Manganous oxide	trace
Lime	12·08
Magnesia	6·04
Potassa	·74
Soda	3·08
	99·84

Analysis shows that in its present state this rock contains a large proportion of carbonate of calcium; and since the lime found is only 5 per cent. in excess of that required by the carbonic anhydride, it follows that the original doleritic material must have undergone extensive alteration.

A section from this locality is represented in fig. 3 (Plate XXI.), in which a group of felspar crystals, magnified 22 diameters, is seen in the centre of the field; below these are numerous cavities filled with calcite, while above them are stains of ferric oxide. The sanidine-like crystals are generally rendered cloudy by products of alteration, and are often divided by fissures which have become filled with calcic carbonate. Less frequently the structure of altered felspar crystals has become to some extent sphærulitic, from the rearrangement of their constituents. These spheroidal bodies, of which the largest are about ·33 millim. in diameter, resemble minute agates, being formed of alternate amorphous and slightly crystalline bands, while their centre is occupied by a transparent substance, into which, when seen in polarized light, minute crystals are observed to converge.

Fig. 4 (Plate XXI.), represents a portion of an altered felspar crystal magnified 14 diameters. Although possessing a distinctly schistose structure, this rock is evidently a lava in which the vesicles are flattened parallel to the planes of foliation.

North-eastern District.—On Treglynn Common is found a rock which in hand specimens appears to be made up of a felted mass of longitudinally striated crystals 5 millims. in length, and of about half that width, of a dark green mineral, possessing a somewhat bronzy lustre. Under the microscope this material, which constitutes nearly two thirds of the rock, is found to be distinctly dichroic, and to be often composed of parallel hornblendic belonites, sometimes terminating in a brush at the extremities, where the belonites are frequently more or less curved. In other cases the character of these imperfect crystals is indicated by parallel lines in the direction of their length, while, less commonly, cleavage-lines, forming angles characteristic of hornblende, are very distinct. With this mineral is associated a triclinic felspar, some of the crystals of which are comparatively unaltered, while others have become partially kaolinized. This felspar is everywhere permeated by belonites of bright-green hornblende, often occurring in radial groups, as well as by patches of subcrystalline viridite. Altered titanic iron is moderately abundant, as is also a nearly colourless transparent augitic mineral; but no apatite was observed. Fig. 6 (Plate XXII.) represents a section of rock from this locality, magnified 14 diameters.

Scaddick Tor, situated two miles further east, is composed of a rock of similar character, but considerably coarser in texture, since the majority of the hornblendic crystals are at least 13 millims. in length. Thin sections are found to differ from those of the foregoing rock only in that the grain is coarser, while felspar is less abundant and partially replaced by a transparent though somewhat milky substance, enclosing grains of quartz, and is without the transparent augitic mineral which sometimes occurs in rocks from this district.

At Trewint, near Five Lanes, a stone was at one time extensively quarried from a broad band of "blue elvan," somewhat closer in structure than that constituting Scaddick Tor, but in other respects closely resembling it. This quarry does not appear to have been worked for some years; but fresh specimens are nevertheless readily obtainable from the rock *in situ*: these afforded, upon analysis, the following results (sp. gr. = 3·04):—

Water { hygrometric	·32
Water { combined	·71
Silica	47·72
Phosphoric anhydride	trace
Alumina	17·72
Ferric oxide	·60
Ferrous oxide	10·71
Lime	10·90
Magnesia	7·89
Potassa	·33
Soda	3·00
	99·90

Sections of this rock are found, under the microscope, to contain no felspar, its place having been apparently taken by a small quantity of a granular ground-mass, which occupies the spaces between bacillar crystals and microlitic aggregations of hornblende; it also contains viridite, some unaltered magnetite, and numerous angular grains of quartz, which do not enclose liquid-cavities.

In its chemical composition this rock is essentially identical with the ancient dolerites from the neighbourhood of Penzance, thus affording an example of rocks chemically alike, differing materially in their mineralogical constitution.

A little north of the main road at Two Bridges is a quarry worked for road-material, upon a rock which is a scarcely altered dolerite. The principal indication of change is the replacement of a large proportion of the ilmenite by the usual greyish-white material and the presence of patches of viridite resulting from the decomposition of augite.

Rather more than a hundred yards east of the church of South Petherwin, and immediately north of the highroad, a large quarry has been opened upon a band of fine-grained greyish "blue elvan," which occasionally encloses spots of iron pyrites. An examination of thin sections shows that it consists, to a large extent, of unaltered plagioclase, with which is associated equally fresh augite. The ilmenite has undergone the usual change; but in other respects this rock, which is a typical dolerite containing no visible apatite, is unaltered.

Although "dunstone" may probably occur in this district, that rock was nowhere observed.

South-eastern District. "*Blue elvans.*"—Writing about the year 1822, the Rev. John Rogers says, "The hornblende formation of St.-Clere (near Liskeard) is principally confined to that elevated land called St.-Clere Down. It extends about a mile from east to west and about half a mile from north to south, and appears to run east and west, and to dip towards the south or south-west. . . . . It may be observed that hornstone and hornblende-slate, passing into clay-slate, are found throughout the whole line of junction [of granite and clay-slate], except towards the north-east, where I found no hornstone. In that direction hornblende-slate, a kind of greenstone-slate, and clay-slate, abounding with particles of mica, form the connecting chain of minerals from hornblende to granite. In this quarter, likewise, in a field adjoining the vicarage garden, towards the west, asbestus has been found in veins in greenstone-slate; but the quarry in which it was found has been filled up for some years.

"The mineral which I have called hornblende-slate graduates so imperceptibly into clay-slate, that I have hesitated which name to give to some of the specimens; it appears to be the slaty felspar rock of Jameson, and has been sometimes denominated purple killas"*.

A specimen of the crystalline coarse-grained rock from St.-Cleer Down, analyzed, in duplicate, in the author's laboratory, by Mr. J. H. Brown, afforded the following results, showing that it has the usual chemical composition of this variety of greenstone (sp. gr. =2·90):—

* "Observations on the Hornblende Formation in the parish of St. Clere," by the Rev. John Rogers (Trans. Royal Geol. Soc. of Cornwall, vol. ii. p. 218).

	I.	II.
Water { hygrometric	·21	·24
Water { combined	1·69	1·53
Silica	47·32	47·21
Carbonic anhydride	trace	trace
Phosphoric ,,	trace	trace
Alumina	18·10	18·19
Ferric oxide	6·21	6·27
Ferrous oxide	7·72	7·66
Manganous oxide	trace	trace
Lime	8·24	8·13
Magnesia	7·05	7·15
Potassa	·62	·50
Soda	3·18	3·27
	100·34	100·15

An analysis of a specimen of the fine-grained green slaty rock from this locality, also made by Mr. Brown for the author, shows that it contains more silica and alumina, as well as a smaller proportion of magnesia, than the crystalline rock.

It therefore follows that, if both had originally a similar composition, one of them at least must have subsequently undergone considerable alteration.

Analysis, in duplicate, of this rock afforded the following percentage results (sp. gr.=2·89):—

	I.	II.
Water { hygrometric	·26	·19
Water { combined	·37	·40
Silica	52·54	52·57
Phosphoric anhydride	trace	trace
Alumina	23·83	23·69
Ferric oxide	2·44	2·50
Ferrous oxide	4·87	4·83
Manganous oxide	trace	trace
Lime	7·89	7·91
Magnesia	2·67	2·74
Potassa	1·95	1·78
Soda	3·11	3·29
	99·93	99·90

The coarser-grained greenstone of St. Cleer-Down does not materially differ from various much-altered rocks of the same class found in other localities. Hornblende is plentiful, both in crystalline patches and in bacillar aggregations, disseminated in a groundmass probably resulting for the most part from the decomposition of felspar, which is usually coloured by viridite.

But little unaltered felspar was observed in the sections prepared from this rock; but patches of quartz, which are apparently imperfect pseudomorphs after that mineral, are sometimes present. These and the various crystalline grains of quartz which occur in this rock are traversed in all directions by hornblendic belonites. Magnetite is moderately plentiful; but apatite is not frequently met with.

The fine-grained varieties, or "hornblende-slates" of Mr. Rogers, have a finely schistose structure, but are exceedingly hard, and break somewhat more easily along certain parallel planes than in other directions. When examined under the microscope they are found to be composed of a colourless material, through which very minute crystalline flakes of hornblende are thickly disseminated together with a little magnetite, quartz, and a nebulous green mineral which high powers resolve into imperfect crystalline forms. These rocks are often traversed by strings and veins of quartz.

At Merrifield, two miles north-east of Liskeard, a quarry is worked on a stone which differs from the coarser rock on St.-Cleer Down, inasmuch as it contains crystals of plagioclase still exhibiting the usual coloured striations when seen in polarized light. This rock also occasionally encloses a few nearly colourless and imperfectly formed crystals of epidote as a product of alteration.

On the left bank of the stream, flowing through the valley half a mile west of Trewolland, is a quarry on the road-side, which is worked for a stone of the usual character, but considerably lighter in colour.

When thin sections of this rock are examined, they are found to consist of crystals of plagioclase which have become externally decomposed into a nearly amorphous substance, which cements them together. If viewed between crossed prisms, these crystals exhibit the usual coloured striations of triclinic felspar, while the cementing material, apparently resulting from their decomposition, frequently exercises no action upon polarized light. In this are disseminated patches and crystalline grains of quartz and calcite, a few flakes of partially decomposed mica, occasional needles of apatite, and a considerable amount of either magnetite or ilmenite.

At Pope's Mill, two miles south-east of Liskeard, is a comparatively coarse-grained dark-coloured rock, consisting of plagioclase, hornblende, and augite with brown mica, a little quartz, apatite, and magnetite. The crystals of these minerals are usually imperfect; but some of the hornblende is evidently pseudomorphic after augite, and, such being the case, must be regarded as uralite.

Two miles south of Callington, on a farm called Scatchell, is a dolerite of which both the felspar and augite have undergone considerable alteration. This rock contains some of the augitic mineral found in that from Hendra Chapel, Camelford, and numerous pseudomorphs after ilmenite.

On Balstone Down, a mile south-east of the town of Callington, stone of a light greyish-green colour is obtained from a quarry immediately north of the turnpike road. Hand-specimens of this rock closely resemble that from Hendra Chapel, and appear to be chiefly composed of a mineral exhibiting, although in a far less degree, the iridescence of bastite. Under the microscope thin sections are seen to be composed of a green monochroic ground-mass largely consisting of viridite, in which slender crystals of hornblende are arranged in stellate and bacillar groups; it also encloses patches of green hornblende distinctly exhibiting the characteristic angular cleavage-striations of that mineral. In this matrix are included crystals of sahlite (?), a little magnetite, and a few minute crystals of epidote.

Smeaton Quarry is situated three miles south-east of Callington, and is worked upon bands of an exceedingly hard stone, generally of a greyish-green colour, which dip towards the south. Interbedded with the greenish rock are bands of a much lighter colour, which are considerably less hard than the darker variety. The darker rock, although in hand-specimens almost identical in appearance with the "hornblende-slate" of Mr. Rogers, is found, on examination of thin sections, to be of sedimentary origin, and to consist of a quartzose ground-mass, through which is disseminated a greenish flocculent material, together with sericite, the whole being occasionally stained by spots of hydrated ferric oxide. This ground-mass encloses numerous rounded grains of quartz, having on an average a diameter of ·16 millim. When examined in polarized light, these are seen to be each made up of numerous angular granules.

The lighter-coloured rock does not materially differ from the other, excepting that it contains but little of the flocculent greenish matter, and that the included granules of quartz are more angular and less numerous.

A little west of Pounder a quarry is worked on a rock which, with the exception of containing patches of quartz and a few grains of calcite, is composed of crystalline augite, plagioclase, and grains of magnetite or ilmenite.

In a field adjoining the main road, a hundred yards north of the church at Landrake, is a quarry, now abandoned, from which a trap of the usual character was formerly obtained. It was found somewhat difficult to procure freshly-broken specimens from this locality; but sections prepared from those collected show that they consist of more or less altered plagioclase, augite, viridite, ilmenite and a few hornblendic belonites; a greyish flocculent product of alteration is disseminated throughout the mass.

A short distance west of the turnpike-road, near Hatt, is a quarry from which stone is obtained for the repair of the neighbouring roads. This rock, which is of the usual colour, is somewhat slaty in texture, and is rather coarse-grained than otherwise. Under the microscope the felspar, which has not generally suffered extensive alteration, is seen to be almost wholly triclinic, while the augite has experienced a species of decomposition by which it has been rendered opaque, excepting along certain irregular lines. This is occasioned by the formation of a dark grey dusty product of alteration which is almost always present in modified doleritic rocks. In some places the plagioclase has become merged into a granular mass, containing patches of calcite, viridite, and hornblende, and enclosing a large amount of altered ilmenite, with numerous crystals of apatite.

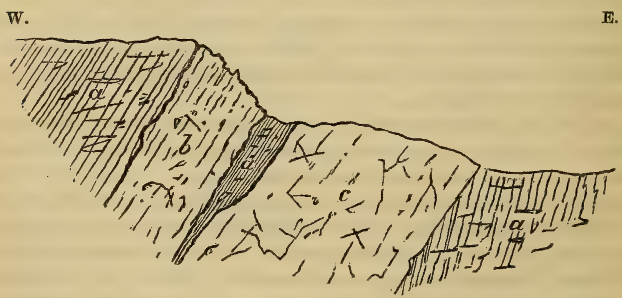
Near Carkeel greenstone is obtained from a quarry situated at a short distance north-east of the road; but this rock has undergone such extensive alteration as to afford but little information relative to its original composition; in its present state it consists of a granular mass, in which numerous indistinct microlites cross one another in all directions. These minute crystalline bodies, however, are rendered opaque by hydrated ferric oxide, the only recognizable minerals being viridite and magnetite.

At Cumble Tor, on the left bank of the river Nottar, nearly opposite Holwood, a quarry is extensively worked upon a fine-grained dolerite, in which the felspar is to a large extent unaltered. The augite, which is not abundant in this rock, is sometimes stained by oxide of iron, while the titaniferous magnetite is generally replaced by the usual light-coloured substance.

This rock is overlain by an ancient lava-flow, which, however, is separated from it by a few feet of slate, the character of which has become considerably modified by the action of the influences to which it has been exposed

The accompanying woodcut will afford an idea of the appearance of the section exposed in Cumble-Tor Quarry, in which *a* represents slate, *b* the lava-flow, and *c* dolerite.

Section exposed in Cumble-Tor Quarry.



a. Slate. *b.* Lava. *c.* Dolerite.

The lava *b* is vesicular, and contains a large amount of comparatively unaltered plagioclase, but no augite, which has apparently become replaced by viridite, and by the flocculent dusty-grey substance which in the rock from Hatt is seen to result from the decomposition of that mineral.

In this quarry there are patches of rock which have become decomposed into a soft yellowish-grey freestone; sections cut from such specimens are found to consist chiefly of a colourless granular material, in which, although shadowy outlines of felspar are sometimes visible, the crystals of that mineral have generally disappeared. Throughout this are disseminated a few small patches of green hornblende, a little viridite, and some of the greyish dust-like mineral which is sometimes seen to result from the decomposition of augite.

On an estate called Grove, situate in the parish of St. Stephens (by Saltash), a mile lower down the course of the river Nottar than Cumble Tor, but on the same side, a quarry was formerly opened upon a band of dolerite of considerable extent and thickness. This rock is rather coarse in its grain, and in hand-specimens appears to consist of a mixture of felspar, in crystals 3 millims. in length, with a dark pyroxenic mineral, also distinctly crystalline and preponderating slightly in amount over the felspar.

In thin sections, examined under the microscope, the plagioclase is seen to be considerably obscured by a flocculent product of alteration, while the augite, which in some instances is entirely without change and well crystallized, is in others almost completely converted into uralite. The magnetite is unaltered; and apatite is comparatively abundant. Sections prepared from specimens obtained from this locality are exceedingly instructive, affording, as they do, examples of the gradual conversion of an ancient dolerite into a uralitic rock—crystals of augite in all stages of alteration being abundant.

Near the hamlet of Burraton Combe, immediately north of Trematon Castle, a band of dolerite has been laid open by a quarry. The rock here met with, in addition to its normal constituents, contains a little viridite, but is apparently without hornblende; its ilmenite is much altered; and it encloses numerous needles of apatite.

Adjoining the limekiln at Anthony Passage, a mile south of Burraton Combe, is a rock consisting of a mixture of plagioclase, augite, hornblende, brown mica, magnetite, and apatite; some portions of this rock, which is very dark in colour, appear to afford indications of its having been originally, to some extent, vesicular.

At Wearde, on the eastern bank of the creek extending up the valley in the direction of Ford, and probably upon the same band of rock, a quarry has been extensively worked for road-material. The stone here obtained varies considerably both in texture and in colour, but is generally made up of a nearly equal mixture of dark crystalline minerals with crystals of felspar, the latter being about 2·5 millims. in length. Less frequently either the felspar preponderates, giving rise to a rock of lighter colour, or the coloured minerals become more abundant, and a very dark green rock is the result.

A specimen of the more abundant variety of this rock, first described, was analyzed, in duplicate, and afforded the following results (sp. gr.=2·89):—

	I.	II.
Water { hygrometric	·32	·30
Water { com ined	2·02	2·00
Silica	46·42	46·37
Carbonic anhydride	2·32	2·31
Phosphoric ,,	·98	·85
Alumina	20·23	20·42
Ferric oxide	4·43	4·45
Ferrous oxide	5·89	6·02
Manganous oxide	trace	trace
Lime	5·99	6·08
Magnesia	3·82	3·87
Potassa	1·95	1·83
Soda	5·00	5·09
Lithia	trace	trace
	99·37	99·59

The coarse-grained variety of this rock consists largely of felspar crystals, of which a considerable proportion exhibit, when seen in polarized light, the striation of plagioclase. In some cases, however, the striæ are either indistinct or entirely absent, while not unfrequently the felspar has become merged into a granular mass enclosing patches of calcite and quartz. Throughout this ground-mass are disseminated flakes of brown mica, some hornblende, and viridite, with grains of magnetite and an unusually large amount of apatite. Mixed with these are numerous small crystals of epidote of a pale yellow colour, which are moderately abundant throughout the mass.

The darker rock from this quarry is much finer in grain than the above, and differs from it only inasmuch as the felspar has generally become decomposed, while mica is more abundant, and a few small patches of some partially altered augitic mineral are present.

The joints and headings which occur in the altered doleritic rocks of the neighbourhood of Saltash, instead of being filled with a brown ochreous clay as in Western and Central Cornwall, are usually coated with a layer of crystalline calcite.

"*Dunstones*."—Vesicular lavas are plentiful in South-eastern Cornwall; but they differ in no respect from those which have been already described as occurring along the northern coast of the county, excepting that their vesicles are more constantly filled with calcite than they are in similar rocks found further north.

Here, as well as in the neighbourhood of Port Isaac, this material is sometimes employed for repairing the roads; and quarries have in various places been opened upon it for obtaining stone for this purpose, as at Polbissick, near Landrake, immediately south of the road at Burrel, and elsewhere. A flow of lava of considerable thickness has also been cut through in making the road near Callington New Bridge, and affords an instructive section.

Conclusion.

In addition to the rocks which occur in Western Cornwall, some of the areas forming the subject of the present paper afford numerous examples of ancient lava-flows so interbedded with the slates and schists of the district as to lead irresistibly to the conclusion that they are contemporaneous igneous products.

These lavas, notwithstanding the alteration to which they have been subjected, closely resemble those of more modern date, and contain cavities which are now filled either with a mixture of viridite and calcite or with quartz through which vermicular chlorite is distributed. They sometimes assume a distinctly schistose structure, and contain crystals of a sanidine-like felspar, many of which are broken, while others have become sphærulitic, through a rearrangement of their constituents.

The crystalline greenstones of Central and Eastern Cornwall afford a more varied and instructive series than is furnished by those of the western portion of the county. Among them are typical dolerites on the one hand, as at South Petherwin, while on the other there are rocks which, as at Carkeel, are so altered as to consist only of a granular indefinite material traversed by indistinct microlitic bodies, and, in patches, stained brown by oxide of iron.

The pyroxenic constituent of these rocks, wherever its crystals admit of identification, is augite; and they are consequently dolerites. By many petrographers they will doubtless be classed either as *diabases* or *melaphyres*; but when it is remembered that they differ from modern dolerites only in age, and by reason of changes consequent upon their greater antiquity, it would appear more logical to call them ancient dolerites.

Like their more modern prototypes, these rocks are often associated with flows of vesicular lava, and have manifestly been produced by the operation of forces in all respects similar to those resulting in the eruption of ordinary dolerites. If, therefore, distinct names be applied to the ancient and modern varieties of this rock, it would appear equally necessary to distinguish in the same way between ancient and modern lavas.

The changes which gradually take place in such rocks are usually the transformation of augite into hornblende and viridite, while the felspar becomes cloudy and finally merges into a granular mass. The titanic iron is also more or less completely replaced by a greyish-white product of alteration; and a little epidote sometimes appears as a secondary product. Some of the grains of quartz found in rocks of this description are probably the result of a dissociation of silica.

The transformation of augite into hornblende often begins with an external hornblendic fringe, and the crystal finally becomes replaced by an assemblage of felted microlites. Less frequently this change commences at one or more points within the crystal itself.

In other cases crystals of augite are gradually replaced in such a way that their outlines are distinctly and sharply preserved, while their substance is replaced by hornblende exhibiting all the distinctive characteristics of that mineral; the rock thus passes into a *uralite-dolerite* or "*uralite-diabase.*"

When the augite in rocks undergoing this species of alteration does not occur in well-formed crystals, the sharp line of division which exists between the altered and unaltered portions might lead to the conclusion that a mixture of hornblende and augite was originally present. The examination, however, of sections containing well-crystallized augite shows that, in addition to this mineral in a partially altered state, perfectly formed crystals of uralite are also frequently present. It therefore follows that, although both augite and hornblende may have sometimes been original constituents of certain rocks, the alteration of augite into uralite has in other cases actually taken place.

A microscopical examination of above two hundred carefully prepared sections from rocks of this class proves that a very large majority of them are altered dolerites. It would, however, have been impossible to classify many of the more altered specimens, had not an extensive series, exhibiting various gradations of change, been available for comparison.

When rocks of this class do not contain augite, and are to a very large extent composed of long bacillar hornblendic crystals made up of parallel belonites, of which the ends are frequently curved outwards, it is possible that this mineral may sometimes have been an original constituent.

The rocks both at Scaddick Tor and at Trewint belong to this class; but on referring to the analysis of the latter, it will be observed that in chemical composition it closely agrees with the altered dolerites of Penzance.

At Pope's Mill, near Liskeard, and at Wearde, in the neighbourhood of Saltash, the crystalline traps contain mica, in addition to their more ordinary constituents.

Slaty or schistose greenstones are of less frequent occurrence in the eastern and central districts than they are in the more western portions of the county. On St.-Cleer Downs, however, the "hornblende-slates" graduate imperceptibly from crystalline dolerite on the one hand, into clay-slates on the other; and instances are by no means wanting where a rock is massive and crystalline near the centre of its outcrop, while externally it is schistose and without visible crystals. These slaty greenstones, or hornblende-slates, as they have been sometimes called, are here exceedingly hard, and have often a structure as compact as that of quartzite; they are somewhat foliated, and break with greater facility along certain planes than in other directions. A microscopical examination of this rock shows it to consist mainly of a transparent colourless material containing grains of quartz, through which are thickly disseminated flakes of a hornblendic mineral, not averaging more than ·05 millim. in diameter; it also contains unaltered titanic iron, and a nebulous green substance which high powers resolve into imperfect crystalline forms. On comparing the analysis of this rock with that of a dolerite from the same neighbourhood, it will be observed that they differ chiefly in the amount of silica, alumina, and magnesia which they respectively contain. Both in hand-specimens and in thin sections all traces of definite crystalline structure have entirely disappeared; but the various progressive changes observed during the examination of an extensive series of these greenstones render the igneous origin of this foliated rock by no means improbable.

The slaty blue elvans found between St. Erth and St. Stephens (in Bramwell) have a chemical composition identical with that of the altered dolerites, and may be, as was formerly suggested, highly metamorphosed ash-beds. They occasionally, however, appear to exhibit indications of having been to some extent vesicular; and recent investigations would perhaps point to the greater probability of their being sometimes true, although much-altered, igneous rocks. The highly basic crystalline slaty hornblendic rocks of the neighbourhood of Penzance sometimes afford traces of former vesicularity; but if, as has been suggested by Mr. Allport, these are likewise of eruptive origin, they must, if originally of the same composition as the neighbouring dolerites, have lost ten per cent. of their silica, and have assimilated a corresponding amount of iron oxides.

De la Beche * regarded such rocks as highly altered ash-beds; but it is not improbable that some of them may have originally been flows of volcanic mud.

No rocks of this character were met with either in Central or in Eastern Cornwall.

There can be no doubt, however, that, under certain conditions, rocks of igneous origin acquire a degree of schistosity which is often exceedingly puzzling to the geologist, as it is sometimes impossible to determine where foliated traps cease, and where metamorphosed slates begin. It is nevertheless certain that many of the foliated rocks intercalated among the greenstones of Western Cornwall must belong to the category of highly altered sedimentary deposits.

The felspar in the slaty agglomerates is almost entirely plagioclase, and is derived from the disintegration of greenstones, and not from that of granite.

The age of these rocks may, for the following reasons, be regarded as being generally greater than that of the granite.

First. The vesicular lavas, as well as many of the slaty hornblendic bands, are evidently contemporaneous with the slates among which they are bedded, while the latter are often either displaced by the granite, or traversed by granitic protrusions in the form of veins.

Secondly. The eruptive dolerites which break through the sedimentary beds do not traverse the granite; but, on the contrary, they are frequently displaced by the latter rock.

The relative ages of the more important Cornish rocks were clearly pointed out in 1839 † by the late Sir H. T. De la Beche,

* Geological Observer, p. 702.

† Geology of Cornwall, Devon, and West Somerset, p. 165.

and the observations made during the progress of the present investigation are in general confirmatory of the views entertained by that accurate observer.

Considering the early date at which the Geological Map of the county of Cornwall was prepared, and at the same time making due allowance for the fact of its being the almost unassisted work of a single individual, the rocks marked "greenstones" have been laid down with remarkable accuracy, although it is true that no distinction is made between lavas, ash-beds, and crystalline traps. The "greenstones" have, however, been made to comprehend not only some altered rocks of sedimentary origin, but also certain hornblendic slates of which it would be difficult to ascertain the original condition. It is almost needless to add that railway-cuttings and other workings made since the date of the survey have exposed masses of rock not then known to exist.

DESCRIPTION OF PLATES XX.–XXII.

Fig. 1. Section of fissile hornblendic rock from Trenewth, near Camelford, magnified 22 diameters (see p. 481).

2. Cavity in lava from Pentire Point, filled with quartz and vermicular chlorite, magnified 30 diameters (see p. 483).

3. Lava from Bokelly, St. Kew, enclosing crystals of felspar, magnified 22 diameters (see p. 484).

4. Section of the same rock, showing crystals of altered felspar which have become sphærulitic, magnified 14 times (see p. 484).

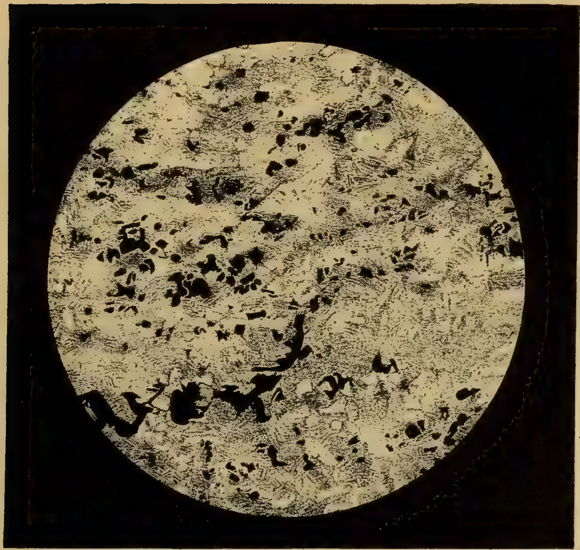
5. Section of a dolerite from St. Minver, near Wadebridge, showing the gradual conversion of augite into uralite, magnified 14 times (see p. 478). This rock is composed of a triclinic felspar, of which a large proportion has become much altered, with augite, hornblende, ilmenite, and occasionally apatite. In the lower portion of the field will be seen a large crystal of partially altered ilmenite, while the augite will generally be observed to have become converted into hornblende, chiefly along some of its edges. In another case this change has begun within the crystal itself.

6. Section of rock from Treglynn Common, west of Scaddick Tor, showing bacillar hornblende, viridite, and altered ilmenite, magnified 14 diameters (see p. 485).

Discussion.

The President expressed his gratification at so valuable a paper being brought before the Society, its importance being greatly enhanced by the working out of the subject both chemically and microscopically. Its peculiar value lay in the demonstration that the ancient lavas came so near to the modern ones.

Mr. Warington W. Smyth said that Mr. Phillips had changed our previous ideas and implanted new ones. One of these was the similarity of the constitution of rocks, some of igneous, some of metamorphic origin, which he thought justified the course taken long ago by Sir Henry De la Beche, who called all these rocks "greenstones." Mr. Smyth also directed attention to the large number of originally pyroxenic rocks in this district, which militated



1.

2.

R. Mintern lith.

Mintern Bros imp.

CORNISH "GREENSTONES."

3.

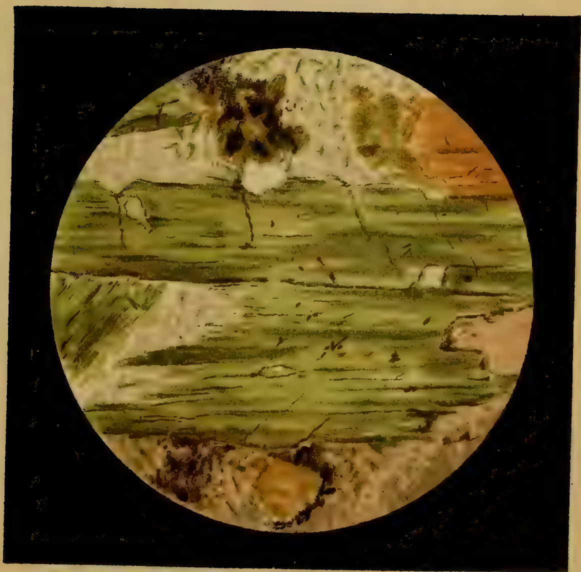
4.

R. Mintern lith.

Mintern Bros imp.

CORNISH "GREENSTONES."

5



6

CORNISH "GREENSTONES."

LITH: L. MERTENS, BRUXELLES.

against the old idea of the greater age of hornblendic as compared with pyroxenic rocks, which was gradually being upset. He thought, however, that there was still much to be made out with respect to the intrusion of these igneous rocks.

Prof. Bonney said that he had frequently observed the same conversion of augite into hornblende described by Mr. Phillips, in Cornwall, Wales, and Charnwood, and in continental rocks. He quite agreed that the Duporth rock was not a true serpentine.

Mr. Sollas stated that he had obtained from near Dartmoor specimens of rocks confirmatory of Mr. Phillips's statements. He inquired whether any connexion could be established between the greenstones and granites.

Prof. Ramsay expressed his gratification at the thorough-going nature of the author's researches, and was especially pleased that Mr. Phillips had found that many of the rocks exhibited such close resemblance as to justify the use of the term "greenstones."

The Author, in reply, stated that the greenstone dykes often seemed to differ in age; but he had seen cases in which one appeared to have been plastic when the other was introduced.

32. *Further Remarks on* Adherent Carboniferous Productidæ. By R. Etheridge, Jun., Esq., F.G.S. (Read March 20, 1878.)

(Communicated with the permission of the Director-General of the Geological Survey.)

1. *Introduction.*

Since I had the honour to communicate to the Society a paper on an "Adherent Form of *Productus*, &c." *, I have obtained evidence that the habit of clinging or attaching themselves by their spines was not simply confined to certain forms of *Strophalosia* and *Productus*, but, there is good reason to believe, was possessed also by a species of *Chonetes*.

Before proceeding to describe the specimens upon which this belief is founded, I wish to make a few supplementary remarks on the adherent *Productus*.

2. *Note on* Productus complectens (*mihi*).

Subsequent researches have shown that the geographical distribution of this species is much more extensive than was at first thought. Mr. James Bennie has obtained some well-preserved examples of the younger state of *P. complectens* at Scremerston Quarry, near Berwick, in Northumberland, on the south side of the Tweed, and he has also met with examples at one or two localities in Fifeshire. I think it not at all improbable that *P. complectens* will be found at one or other of the Lanarkshire localities; for, by the kindness of Mr. J. Smith, Eglington Iron Works, Kilwinning, I have been able to examine two small fragments of Crinoid stems, on which are what appear to be portions of two or three of the small clasping spines, but too fragmentary to pass a definite opinion on. Soon after my description was published, I was favoured by Mr. J. Smith, through Mr. Bennie, with the loan of the subject of Fig. 1, obtained by him at Auchenmade Quarry, near Dalry, Ayrshire. It is a portion of a stem of *Poteriocrinus crassus*, Miller, with at one point a series of spines arranged in a more or less radiating manner from a common central object, which has become obliterated to a large extent or, I think, partially removed. There is, however, at one point a depression in the Crinoid stem partially filled up with a thin layer of shelly matter, which I believe to be the remains of a *Productus*; for the spines are certainly those of that genus; as, however, nearly the whole of the shelly matter has been removed, little more can be said about the specimen. A "Note," calling attention to Mr. Smith's specimen, was communicated to the Natural-History Society of Glasgow by Mr. J. Young, F.G.S.; but as evidence of adherent Productidæ appears to be on the increase, I think it advisable to figure the example. Mr. Young considers this to be specifically

* Quart. Journ. Geol. Soc. vol. xxxii. p. 454.

distinct from *P. complectens*, mihi. This is possible, as the respective forms differ so widely in size; still, the question requires further elucidation. I am glad to find that *P. complectens* is regarded by Mr. Young as a form distinct from hitherto described species.

Fig. 1.

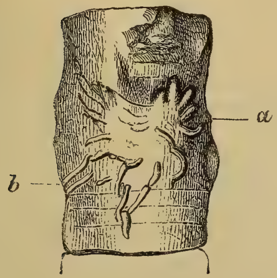


Fig. 2.

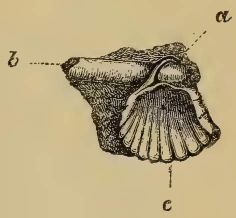


Fig. 3.

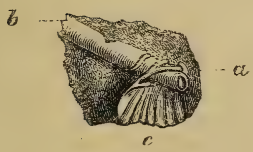


Fig. 4.

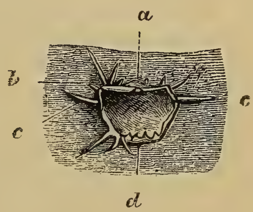


Fig. 1. Portion of stem of *Poteriocrinus crassus*, Miller, with the remains of a large adherent body, probably a *Productus*. *a*, central depression representing the position of the shell; *b*, spines radiating from it. Natural size. Carboniferous Limestone, Auchenmade Quarry, near Dalry, Ayrshire. Cabinet of Mr. J. Smith.

Fig. 2. Small *Chonetes* (?) adhering to a *Productus*-spine by a portion of the visceral region of its shell and three of the hinge-spines. *a*, one of the spines; *b*, *Productus*-spine; *c*, coarse radiating striæ or ridges seen from the interior of the shell. Six times natural size. Carboniferous Limestone, Scremerston Quarry, Northumberland. Cabinet of Mr. J. Bennie, Edinburgh.

Fig. 3. The same, seen from above. *a*, the spines; *b*, the *Productus*-spine.

Fig. 4. Small *Chonetes* (?) or *Productus* (?) adherent on a Crinoid stem, with spines of various lengths radiating from the circumference; the area and fissure are visible. *a*, median fissure; *b*, hinge-spines; *c*, radiating spines from surface; *d*, crenulations along front margin. Four times natural size. Carboniferous Limestone, Fife coast near Kinghorn, Firth of Forth. Collection of Geological Survey of Scotland.

3. *Description of the Specimens.*

The more immediate object of the present paper is to direct attention to the specimens represented by Figs. 2–4. They were both collected by Mr. James Bennie—one during a visit to Scremerston quarry; the other whilst examining a section of the Fifeshire coast near Kinghorn. We have in Figs. 2 and 3 a small Brachiopod, differing in many respects from the adherent *Producti*, but clinging to a *Productus*-spine by its own hinge-spines in such a manner that the interior of the ventral valve is exposed to view. The hinge-line, was, when perfect, in all probability equal to the width of the shell; but in its present state the auricular expansions are to a great extent broken away. The shell is in form roundly oblong and has become attached to the *Productus*-spine not only by its own hinge-spines but also by the umbonal and visceral region, in a similar manner to the mode adopted by *Productus complectens*, mihi. The muscular scars or other internal characters of the specimen are not discernible; but although viewed from the interior, the longitudinal ribs covering the shell are quite visible. Of the latter, there are, I think, about sixteen, large and well-marked for the size of the shell, and one or two perhaps exhibiting traces of bifurcation. In addition to the fixation derived from the union of the visceral portion of the shell with the object of attachment, adherence is effected with the assistance of three spines, differing in size. The largest of these arises immediately from one end of the hinge-line, as far as preserved, and passes directly over and round the *Productus*-spine. The two other spines which assist in the anchoring of the shell, but which are much smaller than the first one named, span the *Productus*-spine in a contrary direction, and are only partially visible.

Unfortunately for the purposes of identification the hinge-line of this little shell is imperfect; but when compared with the adherent *Productus* we see that the mode of attachment is essentially the same, although the longitudinal and radiating ribs give it a character essentially its own, and one not seen in *Productus complectens*. However, before going further with this branch of the subject, it will perhaps be better to first examine the second specimen (Fig. 4).

In this case we have before us also a ventral valve, adhering by the whole of its surface to an Encrinite stem, with a series of spines radiating from it (*c*, *c*), some of the latter, as in the case of those of *Productus complectens*, leaving grooves in the substance of the stem when removed, and showing that in a similar manner a certain amount of increase took place in the Crinoid stem after the shell had attached itself. There may be seen a well-marked hinge-line possessing what seems to be a distinct area and median fissure (*a*), although the latter appears larger than it should do from the accidental fracture of some of the neighbouring shelly matter of the area, but still not sufficiently so to alter its general character. The largest spines (*b*) proceed from each extremity of the hinge-line or area(?), whilst from one side of the shell several others radiate out over the surface of the Crinoid stem, and one or two from the opposite side (*c*, *c*). The state of preservation of this specimen is such that very little more can be said about its general characters, except that along the front there are a few indistinct crenulations (*d*) which may represent radiating or longitudinal ribs on the exterior of the shell. The spines, under the microscope, appear to be of the regular *Productus* type.

4. *As to the identity of the Specimens.*

Returning to that first described, Figs. 2 & 3, we see that for purposes of identification we can rely only on the form, so far as it is preserved, the arrangement of the spines, and the nature of the ornamentation. Taken as a whole, these characters, in this particular case, are decidedly those of *Chonetes*, although the first and last are applicable to both *Chonetes* and *Productus*, but perhaps more to the former than the latter. On the whole I am inclined to regard this specimen (Figs. 2 & 3) as an adherent form of *Chonetes*, although, in the absence of any definite trace of an area or fissure, it may be argued this is rather a premature conjecture. Mr. T. Davidson, F.R.S., was kind enough to examine this specimen shortly after it first came under my notice; and in a letter on the subject, dated 2nd April, 1877, he says, "the little shell in the tube is very interesting, as it shows a small *Chonetes* grasping a *Productus*-spine in a very similar manner to what you have described in *Productus*. I am not, however, quite sure that it is a *Chonetes*; it may be a small *Productus*." Supposing this (Figs. 2 & 3), for the sake of argument, to be a species of the latter genus, it may be asked, With what species has it the greatest resemblance? It appears to me that the decidedly *Chonetes*-like form and longitudinal ribs on the surface of the shell show a tendency towards *Productus margaritaceus*, Phill., with one of the figures of which, given by Mr. Davidson*, it would probably be found to have a certain general resemblance, could we view the shell from the exterior, laid out before us, instead of in its present position. It must, however, be borne in mind that, if the young of a *Productus*, its present form represents what would merely be the extreme umbonal portion of a mature shell; and we must in consequence take into consideration the relative proportions of the longitudinal ribs of the shell in its present condition and in the older form. In other words, I think these ribs, so far as can be judged from an interior of the shell only, are too well marked or defined to be the incipient condition of any of our *Producti*, and accord much better with similar structures seen in the genus *Chonetes*, especially in *Chonetes Buchiana*, De Koninck, a young condition of which I think it not at all unlikely to be.

In the second specimen (Fig. 4) we have, to some extent, more definite characters to depend upon. There are hinge-spines, as in the former case, there is fair evidence of an area, and the remains of a fissure of some kind or other (although this has undergone partial mutilation)—all characters which point towards *Chonetes* rather than *Productus*; on the other hand, I can see no trace of articulating teeth, and I have quite failed to trace a continuation of the spines along the area, although I am less inclined to lay stress on this point, as the spines in question are often broken off in *Chonetes*

* Mon. Brit. Carb. Brach. t. 44. f. 6 & 7.

without leaving any very definite trace of their existence. A much stronger point against the *Chonetes*-affinity of Fig. 4 lies in the presence of the long spines which protrude from the general surface of the shell and are now compressed along the surface of the Crinoid stem; for, so far as I know, there is no distinct evidence that *Chonetes* possessed such spines, but a series of small prickles scattered over the radiating striæ of the valves, as in our common *C. Laguessiana*, De Koninck*. Nevertheless, in his generic description of *Chonetes*, Prof. James Hall says, "it has been ascertained that spines sometimes occur on the body of the shell"†. Again, there is another point worthy of notice in connexion with the spines in Fig. 4. Speaking of the difference between these structures in the two genera *Productus* and *Chonetes*, Prof. de Koninck says that, in the former, the spines are long, straight, cylindrical, and open at the extremity, but in the latter they are usually short, recurved, pointed, and closed ‡; now it is quite apparent that of the two the spines in Fig. 4 agree more closely with Prof. de Koninck's definition of those of *Productus* than of *Chonetes*.

The family Productidæ consists of the following genera or subgenera, as the fancy of the reader may induce him to regard them, viz. *Chonetes*, *Aulosteges*, *Strophalosia*, *Productus*, and *Productella*; and it may be roughly divided, for the purpose we now have in view, into two sections, according to the presence or absence of an area and foramen.

Area and foramen absent.	Area and foramen present.
Productus.	Chonetes, *Fischer*. Aulosteges, *Helmersen*. Strophalosia, *King*. Productella, *J. Hall*.

Granted that the parts I have described in Fig. 4 as the area and foramen are such, we may at once dismiss *Productus* from further consideration, although I do not overlook the fact that an area has been described and figured in some species of the genus §; still it is the exception and not the rule, and it becomes a question for Brachiopodists to what extent restriction on this point should be carried in the genus *Productus*.

I think little need be said as to any resemblance, on the contrary, between Fig. 4 and *Aulosteges*; for the very well-marked difference in the form of the area at once separates them.

* I adopt the name *C. Laguessiana*, in preference to that of *C. hardrensis*, for our common Carboniferous *Chonetes*, in deference to the opinion of Prof. de Koninck, although I quite fail to appreciate the differences which are said to exist between the two forms.

† Pal. N. York, iv. p. 152.

‡ Mon. *Productus* et *Chonetes*.

§ *P. semireticulatus* (Davidson, Mon. Carb. Brach. t. 43. f. 5), *P. costatus* (Hall, Pal. N. York, iv. p. 149), *P.* (? *Productella*) *Murchisonianus*, De Koninck (Mon. *Productus* et *Chonetes*, t. 16. f. 3), *P.* (? *Productella*) *subaculeatus* (*ibid.* t. 16. f. 4, *b*), *P. horrescens*, De Verneuil (Geol. Russia, ii. t. 18. f. 1, *a*), &c.

Turning to *Strophalosia* we observe that the hinge-line is proportionately shorter than in Fig. 4; the area is, again, different in form, and there are, so far as we know, no hinge-spines in *Strophalosia*, although the presence or absence of hinge-spines has been treated by Mr. Davidson as a character not of generic importance*. Still where, as in the present instance (Fig. 4), we are precluded from using the characters of either the muscular or reniform impressions, or even the cardinal process, we must seize upon those exhibited, however trivial. There is, notwithstanding, this resemblance with *Strophalosia*—a species of the latter has been shown by Geinitz to be adherent by its spines.

Lastly, we have to take into consideration *Productella*. This genus, or subgenus, was established by Prof. Hall for Devonian species of *Productus* with a narrow hinge-area, small teeth and sockets, and reniform vascular impressions resembling those of *Aulosteges*†. The linear hinge-area and foramen visible in Fig. 4 might as well represent those of *Productella* as of *Chonetes*, especially as we have no conclusive evidence of a pseudo-deltidium. *Productella* possessed spines along the hinge-line, as in *Productus*, but not on the upper edge of the area, as in *Chonetes*; and, further, the presence of spines in Fig. 4, radiating from the body of the shell, again indicates a closer alliance with *Productella* than with *Chonetes*.

In conclusion, I think, from the evidence afforded by the specimen from which Figs 2 & 3 are taken, we may venture to assume the former existence of another member of the Productidæ, exclusive of *Productus* and *Strophalosia*, which, either during the whole of its existence or some part of it (we do not know which), lived adhering to foreign bodies by its spines and some portion of its shell, and that fair evidence exists of the probability of this form being referable to the genus *Chonetes*. Fig. 4 may or may not be a *Chonetes*; my friend Mr. T. Davidson, F.R.S., is inclined to regard it rather as a *Productus*. As the state of preservation is not so satisfactory as it might be, it will perhaps be better to leave it an open question for the present. Is it a *Productella*?

As to the habit of *Chonetes*, Prof. de Koninck believes that, in the young state, short and fine fibres issued from the fissure, by means of which attachment took place, the shell becoming free only at an advanced stage of its existence‡. He is supported in this view by M. de Verneuil, who appears to follow de Koninck very closely in his views as to *Chonetes*§.

Although I have examined a large number of well-preserved specimens of *Chonetes Laguessiana*, De Koninck, I have never succeeded in detecting oblique tubes traversing the area in connexion

* Introduction to Brit. Foss. Brach. p. 114.
† Pal. N. York, iv. p. 150.
‡ Anim. Foss. Tert. Carb. Belgique, p. 208.
§ Geology of Russia, ii. Palæontol. p. 239.

with the spines as represented by Keyserling in *Chonetes? comoides*, Sow.*, or by Hall in *C. scitula*†.

Locality and Horizon.—Fig. 1, Auchenmade Quarry, near Dalry, Ayrshire; Carboniferous Limestone; collected by, and in the cabinet of, Mr. J. Smith. Figs. 2 & 3, Scremerston Quarry, near Berwick; Carboniferous Limestone Shale. Fig. 4, shale below the second limestone (probably the equivalent of the No. 1 Limestone of Mid-Lothian) on the shore of the Firth of Forth, near Kinghorn, Fife, L. Carb. Limestone group. Collected by Mr. James Bennie.

Discussion.

Mr. Hicks remarked that the range in time of some species of Brachiopoda was very great, and deprecated the creation of new species in this group, except when such a course was shown to be absolutely necessary.

Mr. Etheridge said that *Chonetes hardrensis* seemed to be quite distinguishable from *C. Laguessiana*, and to characterize a distinct geological horizon. He quite agreed with Mr. Hicks in his objections to the creation of new species when there was no real distinction.

* Reise in das Petschora-Land im Jahre 1843, t. 6. f. 1 *c*.
† Pal. N. York, iv. t. 22. f. 11.

33. *On the* Geology *of* Gibraltar. By A. C. Ramsay, LL.D., F.R.S., and James Geikie, LL.D., F.R.S. (Read March 6, 1878.)

[Plate XXIII.]

Contents.

Introduction.

At the request of the Colonial Office, we visited Gibraltar in the autumn of 1876, for the purpose of inspecting and reporting upon the water-supply to the town and garrison. In order to do adequate justice to this important subject it was found necessary to make a complete geological survey of the Rock, and to lay down the details on a map in the usual way, and also to construct a series of sections on a true longitudinal and vertical scale. The report subsequently furnished by one of us to the Colonial Office contained a general account of the geology of the Rock; but from this many interesting details were necessarily omitted, as only those features which bore more or less directly on the question of water-supply were treated of at length. It is the object of the present paper to give a more detailed account of our observations, and to point out the very remarkable connexion which seems to us to obtain between certain Pleistocene deposits of Gibraltar and the glacial accumulations of the mountainous regions and more northerly latitudes of Europe.

The most detailed account of the geology of Gibraltar which has appeared is that given by Mr. J. Smith, of Jordan Hill, in an early volume of this Society's Quarterly Journal. Mr. Smith's paper is of considerable value, more especially as it contains an account of various deposits which are now no longer visible, the operations of quarrying, scarping, and building, which are always going on, having necessarily resulted in the obliteration of some interesting geological evidence.

We append a list of the various papers relating to the geology of the rock which are known to us. There may be accounts of the peninsula by Spanish geologists, but these we have not seen; and perhaps other papers by English authors may have escaped our notice.

"Mineralogical Description of the Mountain of Gibraltar," by Major Imrie. Edinb. Roy. Soc. Trans. vol. iv. (1798) p. 191.

"Notice concerning the Tertiary Deposits in the South of Spain," by James Smith, Esq. (of Jordan Hill). Quart. Journ. Geol. Soc. vol. i. p. 235.

"On the Geology of Gibraltar," by James Smith, Esq., of Jordan Hill, F.G.S. Quart. Journ. Geol. Soc. vol. ii. p. 41.

"On the Geology of Malaga and the southern part of Andalusia," by Professor D. T. Ansted, M.A., F.R.S., F.G.S. Quart. Journ. Geol. Soc. vol. xv. p. 585.

"On the Evidences of Recent Changes of Level in the Mediterranean Coast-line," by George Maw, Esq., F.L.S., F.G.S., &c. Geol. Magazine, vol. vii. p. 548.

"On the Fossil Contents of the Genista Cave, Gibraltar," by G. Busk, Esq., F.R.S., F.G.S., and the late Hugh Falconer, M.D., V.P.R.S., For.Sec.G.S. Quart. Journ. Geol. Soc. vol. xxi. p. 364. See also same paper, with additional notes, "Palæontological Memoirs and Notes of the late Hugh Falconer, A.M., M.D.," vol. ii. p. 554.

Mr. Busk has a paper "On the Caves of Gibraltar in which Human Remains and Works of Art have been found" in the volume of the Prehistoric Congress at Norwich in 1868 (1869).

"Quaternary Fauna of Gibraltar," by George Busk, Esq., F.R.S., Zool. Trans. vol. x. part 2, 1877.

Physical Description.

The Rock of Gibraltar, as every one knows, forms a well-marked promontory that trends in a direction south by west into the Mediterranean. The extreme length of the Rock, measured from the base of the cliff at the North Front to Europa Point, is only a little over 2½ miles, and the promontory tapers somewhat gradually away from a breadth of 1550 yards between Gibraltar and Catalan Bay to a width of 550 yards at Europa. The Rock shoots abruptly upwards from the low flat ground at the North Front in a fine mural precipice, the basal portion of which is partly concealed by a sloping curtain of débris and breccia. This precipitous wall culminates in a height of 1349 feet at the Rock gun, from which point the dividing ridge or backbone of the promontory extends southwards in a sharp jagged *arête*, the dominant points of which are Middle Hill (1195 feet), Signal Station (1294 feet), heights above Monkey's Alameda (1396 feet), and O'Hara's Tower (1370 feet). At the latter the ridge is abruptly truncated, and succeeded to the south by the well-marked plateaux of Windmill Hill and Europa. From the Rock gun to O'Hara's Tower the dividing ridge presents to the east a bold escarpment, which is for the most part inaccessible, and in places almost vertical, the cliffs where they are lowest having a drop of not less than 300 or 400 feet, and of more than 1000 feet where they approach the sea on the north. From their base the ground falls rapidly away to the coast-line at angles that vary from 30° to 40°. The opposite slopes of the dividing ridge are not so abrupt, the only really precipitous portion that faces the west being the line of cliff which overlooks Gardiner's Road and Engineer Road, between the Moorish Wall and the Mount. A low sandy plain, that does not average more than 10 feet in height above the sea, connects the Rock with the mainland.

Rocks entering into the formation of the Promontory.

The rocks of which the famous promontory is composed consist of:—1. Limestone; 2. Shale, with intercalated beds and bands of grit and hardened mudstone; 3. Limestone-agglomerate; 4. Bone-breccias; 5. Calcareous Sandstones; 6. Sand and loose débris. Of these, 1 and 2 are probably of Lower Jurassic age; the others are all of much more recent date, being in fact mere superficial accumulations.

The strike of the limestone and shale undulates gently from north to south, and thus corresponds with the trend of the promontory. From the North Front to the termination of the great escarpment the dip is westerly, generally at a high angle. In some places, however, it is quite vertical, as in the neighbourhood of Monkey's-Cave Road. Vertical dips of the shales and grits are also well seen on the beach between Jones's Battery and Jumper's Battery. In Windmill-Hill and Europa Flats the beds dip persistently towards the east.

More than three fourths of the promontory are occupied by the basement rock, which is a greyish-white or pale grey, compact, and sometimes finely crystalline limestone, arranged in more or less regular beds that vary in thickness from a few feet to many yards, the rock becoming in some places apparently amorphous, so that, were it not for abundant jointing, monoliths of almost any dimensions might be obtained from it. Frequently the bedding is very obscure, and can only be detected when viewed in a good light from some little distance. Here and there the rock has a striped or banded appearance, the bands (which are usually somewhat darker than the main mass of the rock) varying in thickness from an inch or two upwards. In some places, also, thin ribbons of cherty limestone and chert present themselves; and layers and partings of shale occasionally occur, but they are certainly not common. Now and again the rock seems made up of angular and subangular grit and small fragments of grey limestone, agglutinated together in a paste of the same material, and looking not unlike some of the coral-rock of modern reefs. In various places, especially along the crest of the ridge and in the Europa district, the limestone is often brecciiform, an appearance to which further reference will be made in the sequel.

Fossils appear to be of unfrequent occurrence; but casts of *Rhynchonellæ* and what appeared to be encrinital stems were noted, and here and there on weathered faces the small angular fragments or grit of which the rock is now and again composed seemed to consist in some measure of rolled bits of shells. The only good specimens we obtained were given to us by Mr. E. Roberts, C.E.*; all of them came from the quarry at the North Front, and are of one species, somewhat resembling *Rhynchonella concinna*, which is abundant in England in the Cornbrash and Coral Rag †.

The limestone is overlain by a series of shales, which are usually of a dull dark greyish-blue colour. Near their junction with the limestone they are often much weathered, and show red, green, purple, yellow, grey, and particoloured shades. In some places they would work up into clay for brick-making purposes. They contain intercalated bands and beds of grit, mudstone, and limestone, some of the grits being slightly calcareous. Near the base of the series the intercalated limestones are of considerable thickness and closely resemble the main limestone; they appear, however, to thicken and thin out very rapidly. Further up in the series the calcareous beds are thinner and seem to be more persistent; at the same time they become more impure, and are rather calcareous grits than limestones. No fossils have been met with in either the shales or the intercalated beds.

The shales and accompanying beds are best seen upon the beach between Careening Bay and Jones's Battery; good exposures also occur at many points along the junction between the shales and the underlying limestone, for example, at the Upper-Road Tank, at Windmill-Hill Barracks, and the Devil's Bellows. The same series is also well exposed in the cliffs and banks at Camp Bay, where the dip is apparently *under* the limestone.

Before proceeding to notice the limestone-agglomerates and other superficial deposits and accumulations, it will be well to describe the accompanying Sections (figs. 1–7), which will suffice to show the geological structure of the promontory; and we shall add a few notes on the rocks of the neighbouring Spanish territory and opposite African coast.

Description of Sections across the Rock.

Section No. I., from the Mediterranean on the east, crosses the battery on the topmost point of the ridge overlooking the North

* To Mr. Roberts we are under great obligations for much valuable assistance. His position as engineer to the Sanitary Commission has naturally given him the best opportunity of becoming familiar with the geology of the Rock. His minute acquaintance with the ground occupied by the town was of special service to us, as it enabled us to draw our lines with a precision which would have been otherwise impossible.

† The specimens were examined by Mr. Etheridge and Mr. Davidson, who could not with certainty determine the species, though both agreed that they were allied to *Rhynchonella concinna*.

Front, and passes westward to the Old Mole Head. At the eastern end of the section the limestone dips a little north of west at angles of from 12° to 20°. Further west the strata gradually curve to a higher angle, and finally dip under the shale at an angle of about 83° on the ground between the Grand Casemate Square and the Inundation.

Section No. II., from Catalan Bay across Middle Hill to Wellington's Front, very closely resembles Section No. I. in the arrangement of strata both of limestone and shale. The direction of the strike, however, has gradually curved, so that here the dip is about 15° south of west. Mr. Smith accounts for this change of dip by inferring the existence of a fault across the ridge. Of this fault, however, we could find no trace, but were able to follow the beds continuously from the one line of section to the other. It will be noticed that in Section No. II. the limestone and shale where they join are still nearly vertical.

Section No. III. crosses the ridge at St. Michael's Gate at the east end of Charles V.'s Wall, and passes through the Alameda Gardens to the sea a little north of Careening Bay. The south-westerly dips of the limestone on the ridge, on either side of this section, vary from 47° to 65°. The shales that overlie the limestone are concealed by the red superficial sands of the Alameda Gardens, but are well seen in a vertical position, at low tide, at the north end of Careening Bay, between the breakwater and the fortifications.

Section No. IV. crosses the ridge at O'Hara's Tower, and passes westerly to the sea between the New Mole Head and Rosia Bay, near which it is believed to cross a fault, which throws the shale down on the north-east against the limestone. At and near O'Hara's Tower the westerly dip of the limestone is even higher than that of the limestone at the top of the ridge in Section No. III.; for near O'Hara's Tower it ranges from 65° to 75°, and finally dips under the shales and intercalated grits at the Engineer Road, about 150 yards east of the Mount.

With regard to these Sections (I., II., III., and IV.), it will be observed that on the east, below the precipitous part of the Rock, the limestone is in places unconformably overlain by limestone-agglomerate, on which lie the blown sands and loose rock-débris of Catalan Bay and Sandy Bay.

On the west, the ground immediately below great part of the town, we were informed by Mr. Roberts, consists of superficial sand (which has been proved when excavating for foundations), and which is similar to that so well seen in the Alameda Gardens, where at its eastern edge it seems to rest on limestone-agglomerate, in the manner shown in Section No. III.

On the north side of Section No. IV. the limestone-agglomerate, from 50 to 100 feet thick, overlies a large portion of the shale between the New Mole Parade and Europa Main Road, and is continued further south to the sea between Rosia Bay and the New Mole Head.

Between the main mass of the limestone of O'Hara's Tower and the Windmill-Hill Flats, there are several faults which influence the physical geography of the Rock, especially that part which lies south of the Great Main Fault, which runs across the Rock from sea to sea in the manner shown in the map (Pl. XXIII). This main fault may be seen on the coast cliff a little south of No. III. Europa AdvanceBattery, whence it trends through the Devil's Bellows and the Naval Hospital to the sea near the New Mole Head. The proof is as follows :—

The shale overlying the limestone can be traced from the Casemate Barracks through the Town Range Barracks, and at the back of the Upper Road Tank to a point on the Engineer Road a little south-east of the Mount. There the continuity of this boundary is interrupted by a short fault running north-north-east, which on the westerly side of the fracture throws the shale directly against the limestone north-west of Viney Cottage Quarry. Two other north-east faults at and near the Devil's Bellows and Windmill-Hill Barracks throw in a rectangular mass of shale bounded on all sides by limestone, only its northern edge being a natural boundary, whilst all the rest are faults, one of which is the Great Main Fault previously mentioned.

South of this Great Main Fault, all the way to Europa Point, the dips of the strata suddenly change their direction; for between that fault and the North Front the dip of the limestone is always westerly, as shown in the Sections I. to IV., excepting in a small area between O'Hara's Tower and the fault, where the beds stand vertically. Between the main fault, however, and Europa Point the dips of the limestone are very nearly east, as may be seen on the Devil's Bowling Green, on Windmill-Hill and Europa Flats, and all round the coast cliffs from Camp Bay by Europa Point to the Great Main Fault, where it passes under the Mediterranean Sea. The angles vary from 25° to 65°, as shown on the map and Sections Nos. V., VI., and VII.

It appears to us that, south of the fault, the forces that disturbed the strata have in this area been sufficient to turn the limestone fairly over with a reversed dip, so that the uppermost beds as originally deposited now dip underneath strata that originally lay below them.

This view seems to be confirmed by the occurrence of two small patches of shale at Camp Bay and Little Bay, which dip eastward under the limestone, and are thrown against it on the north by two faults, each of which is a downthrow on the south.

The structure of the southern end of the Rock is shown in the Sections Nos. V., VI., and VII.

In Section No. V., south of O'Hara's Tower and near Monkey's Cave, the beds of limestone are shown standing vertically; next comes, at Windmill-Hill Barracks, the faulted rectangular patch of shale already mentioned, west of which, as far as Camp Bay, the limestone dips east about 45°, and is, to a great extent, overlain by the limestone-agglomerate, so well seen in the rugged gorges or dry gullies that traverse the Rock between Camp Bay and Europa Pass.

, Plate XXIII.

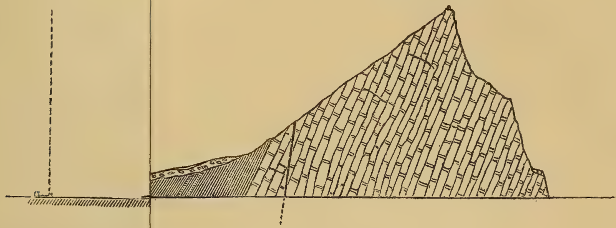
W.

Old Mole.

Fig. 4.—*Section IV.*

O'Hara's Tower,
1370 feet.

E.



Fault.

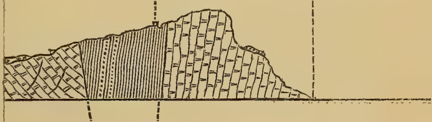
Fig. 5.—*Section V.*

W. Wellington
Front.

Windmill-Hill Barracks,
615 feet.

Coast near
Monkey's Cave.

E.

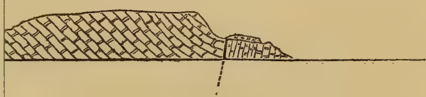


Fault. Fault.

Fig. 6.—*Section VI.*

indmill-Hill Flats, 370 feet.

E.



Fault.

W.

Alam
Gard

Fig. 7.—*Section VII.*

Europa Flats, 115 feet.

E.

Sections across the Rock of Gibraltar along the lines indicated on the Map, Plate XXIII.
(Scale 3⅗ inches to 1 statute mile.)

Fig. 1.—*Section I.*

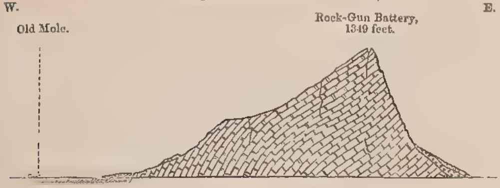


Fig. 2.—*Section II.*

Fig. 3.—*Section III.*

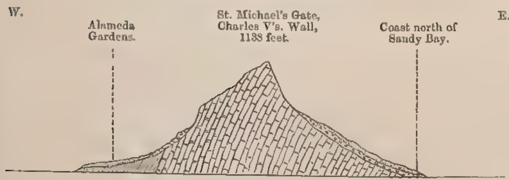


Fig. 4.—*Section IV.*

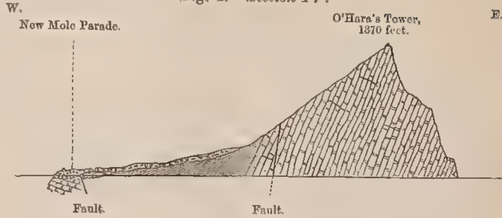


Fig. 5.—*Section V.*

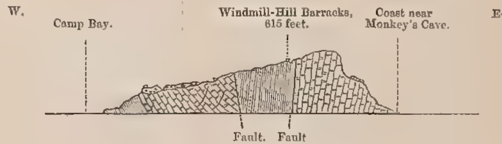


Fig. 6.—*Section VI.*

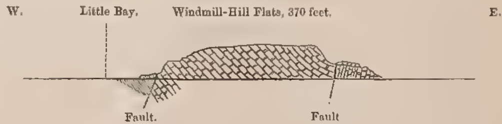
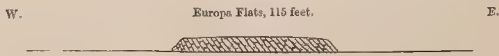
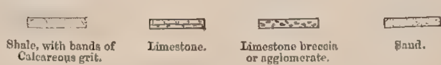


Fig. 7.—*Section VII.*





Further west, in Camp Bay, the shale with thin beds of limestone and grit dips under the great mass of limestone in an abnormal manner, its natural position being above that rock, as shown in the same section at Windmill-Hill Barracks, and in Sections Nos. I., II., III., and IV.

Section No. VI. shows a somewhat similar arrangement of the strata on the eastern side of the main fault at and near the battery above the cliff at Europa Advance Road; the limestone beds stand vertically, overlain in part by agglomerate, and on the southern side of the fault the strata dip easterly at angles varying from 32° to 80°.

Section No. VII., across Europa Flats, shows the same easterly dip of the limestone.

Notes on adjacent tracts in Spain and on the opposite African coast.

The sandy plain that lies between the North Front and the Sierra de Carbonera is about 2 miles in length and more than 1000 yards wide south of the British lines, rather more than a mile wide at Linea, and somewhat more than 2 miles wide from east to west at Pachon. Between the Rock and the ground around Linea the country is nearly flat, having an average height of about 10 feet above the level of the sea. Further north, towards the Spanish hills, this average elevation is varied by the occurrence of low dunes of blown sand.

North of this plain there rises the hilly ground of the Sierra de Carbonera, the Queen of Spain's Chair, 971 feet in height, forming a prominent point in the landscape. From the neighbourhood of the "First Tower," on the east, to the River Lavo and the mouth of the Guadaranque, the rocks consist chiefly of beds of sandstone and shale, with limestone at one place, the sandstones, on the whole, predominating. The prevalent dips are south-west and west; but occasionally the beds dip easterly, as shown in the ground in places between Pachon and the Queen of Spain's Chair. East of Pachon, however, the sandstone strata north of the sandy plain seem for a small space to dip to the south. The alternating strata of sandstone and shale of the coast of the Bay of Gibraltar are well seen on the shore at low tide, at and near Punta Mala and at Rocadillo Tower, where the strike of these beds trends more or less towards the shaly ground that overlies the limestone rock of Gibraltar.

South of the wide alluvial plains and sandy hills of Guadaranque and Palmones, the strata between Punta del Reconcillo, Algeciras, and Sandy Bay consist chiefly of red, green, yellow, and grey clays, shales, and marls with ribs, bands, and beds of sandstone and mudstone, some of the intercalated sandstone bands being somewhat calcareous, as at Almirante Tower. The same kinds of strata of shale and sandstone form the interior of the country west of Algeciras, as far as the waterfall on the river Miel, and apparently much further.

The general strike of the beds along the north coast of Gibraltar

Bay is southerly, and at and near Algeciras more or less easterly; but the strata are now and again much contorted and confused; the prevailing dip, however, along the west coast of the bay appears to be a little west of north. There can be no doubt that, underneath modern superficial marine deposits, the bed of the bay is occupied by sandstones and shales, similar to those of the Spanish ground just described and those of the west coast of the Rock of Gibraltar.

North of the Sandy Plain the strata of the Steeple Chase, the Queen of Spain's Chair, and the neighbouring country consist, as we have said, of thick beds of sandstone, with interstratified beds of shale, which dip chiefly westerly, with some contortions, and finally, east of Pachon, pass under the sands of the plains, apparently with a southern dip, which, however, may be only local.

The question thus arises, Do these sandstones extend beneath the sands of the plain towards the limestone rock of the North Front?

By reference to the geological map (Pl. XXIII.) it will be seen that the strike of the limestone and overlying shale gradually curves in the neighbourhood of Grand Casemate Square; for whereas south of the Square the strike runs from south to north, beyond the Square along the Inundation the strike of the strata bends round in a north-easterly direction. This change of strike has been proved by actual observation along the south-eastern side of the Inundation; but beyond that, across the Racecourse, nothing further is known.

If, however, the strike of the shale and limestone be continued on the assumption that they partly occupy the ground beneath the superficial sands, then the Cemetery and the ground further east, to the shore, a little further than the north-east corner of the British lines, will be underlain by limestone, and part of the territory immediately to the west and north underneath the sands will consist of shales and intercalated calcareous grits &c., similar to those that lie on the west side of the limestone of Gibraltar itself.

It may, however, be questioned whether the limestone does extend northwards to any great distance beyond the bold cliff of the North Front; and, after much deliberation, we thought it most probable that a large fault, running about 23° north of east, cuts off the limestone along the line, roughly speaking, of the Devil's Tower Road, and passes into the bay somewhere about the Stone Jetty on the western shore of the Isthmus. (This supposed fault is shown on the map by a dotted line.) If this be so, then the fault is a downthrow on the north; and it is quite possible that it may be of sufficient amount to throw the limestone, which underlies the shales, so far beneath the surface, that the sandstones and shales of the Spanish hills may underlie the sands of the Isthmus and abut upon the limestone of the Rock on the southern side of the fault. Considering the excessive disturbance of the strata of the Rock itself, and the phenomena attendant on the Great Main Fault that traverses it south of O'Hara's Tower, and also the intense disturbance and contortion of the strata north and west of Gibraltar Bay, such a fault as that inferred beneath the sands of the North Front is not more remarkable than some of the phenomena visible elsewhere at the surface. Great leading faults are apt to be parallel, and the inferred fault is parallel to the Great Main Fault.

At Campo there is a good exposure of arenaceous clay or argillaceous sand, charged abundantly with molluscan shells (one of which is *Terebratula grandis*), *Echini*, and other organisms. The deposit is probably of Pliocene age. Mr. Smith makes some reference to the occurrence of rubbly sandstone beds immediately to the north of the Sandy Plain, in which he found abundant marine Tertiary fossils, referred by him to the Miocene. The particular place he alludes to we did not see; but there is no doubt that the deposits at Campo rest quite unconformably upon the sandstones of the Queen of Spain's Chair and that neighbourhood.

Of the more recent deposits to be met with round the shores of the Bay of Gibraltar it is not necessary to speak. There are wide spreads of modern alluvium in the valleys of the Guadaranque and Palmones rivers; and at higher levels occur older alluvial terraces. It may be worth noting also that at the cemetery near Almirante Tower, red loess, apparently of some considerable thickness, covers all the low grounds that rise from the coast towards the foot of the hills.

Here it may not be out of place to mention what we saw of the rocks on the opposite coast of Africa.

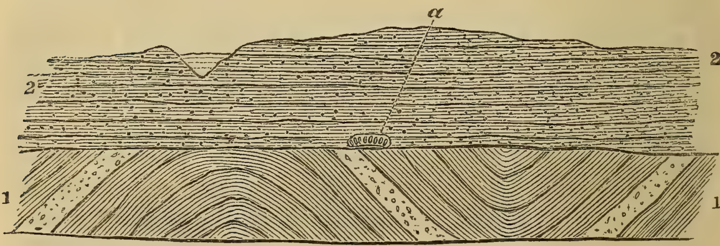
By the kindness of the naval authorities at Gibraltar we crossed to Ceuta in the gunboat commanded by the Hon. Algernon Littleton, being accompanied by several members of the Sanitary Commission.

About 4 miles from the town we came upon blue slaty rocks, not unlike the Lower Silurian strata of Wales; and apparently interstratified with these were beds of hard grit and many veins of quartz, one of which is a lead-lode now being worked. Though very much contorted, these strata apparently dipped westerly under the strata associated with the mass of Abyla, called by the English Ape's Hill. This mountain has a height of 2308 feet, and forms the African Pillar of Hercules, as opposed to that of Gibraltar. Coasting along the shore, it was easy to see that Abyla consists of limestone similar to that of Gibraltar, and quite as much disturbed. The strata of both the Pillars strike towards each other, and the shales and sandstones both below and above the limestone apparently closely resembled those of the Spanish hills of the Queen of Spain's Chair and the contorted shales and grits that surround the Bay of Gibraltar and form the hills behind Algeciras. Such-like strata apparently form the coast-cliffs as far as the neighbourhood of Tangier, and from thence 12 miles further to Cape Spartel, which latter distance we rode. Immediately west of Tangier the strata consist of shales, which dip under sandstones forming rounded undulating hills of about 800 feet in height. The strata dip in various directions, southerly, westerly, &c.; and at Cape Spartel the sea-cliffs are formed of white sandstone, with ferruginous springs, like some of our Coal-measure strata. We presume, however, that, like the Abyla, Gibraltar, and Algeciras strata, they are probably all of Jurassic age. From the tops of the hills to the east of Tangier one could see that the Abyla or Gibraltar limestone ranged south for many miles, forming a mountain-ridge easily distinguishable from the other hills in its vicinity by its jagged form and sepulchral-grey hue.

While coasting along in the gunboat we observed what seemed to be two distinct marine terraces of elevation, which may possibly be equivalent to those of Europa and Windmill-Hill Flats. In connexion with this subject, we mention the following interesting circumstance.

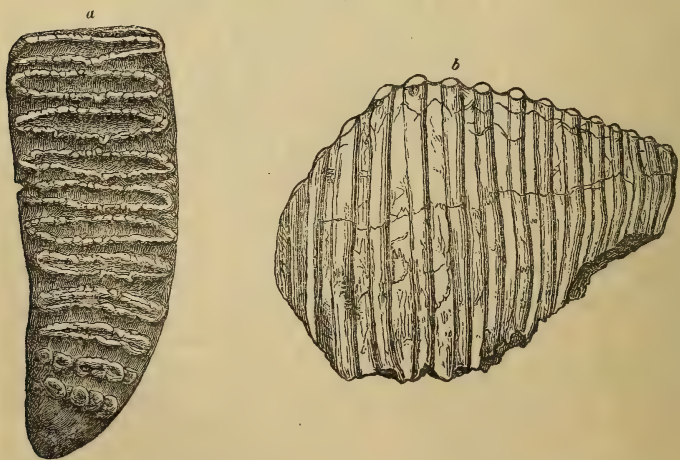
Close to Victoria Hotel, one of the gates of Tangier opens on a short road, which leads to the sea-shore, above which there is a low cliff, which shows a clear section of the strata; thus (fig. 8):—

Fig. 8.—*Section of Cliff near Tangier.*



1. Contorted beds of shale and grit.
2. Semiconsolidated coralline and shell sandy beds, with small pebbles.
a. Indicates the position in which a tooth of *Elephas antiquus* was found.

Fig. 9.—*Right ultimate upper molar of* Elephas antiquus *from near Tangier.*



a. Crown, one third natural size. *b*. Side view, one fourth natural size.

The shale and grit marked 1 resemble those that overlie the limestone of Gibraltar, and after disturbance have been planed across, apparently by marine denudation, before the deposition of the strata marked 2, so that the same bed of grit occurs three times in the section. The upper surface of the shale and grit is about 12 or 15 feet above high-water mark, and the whole length of the cliff is about 35 feet. Beneath the point marked *a* our party, consisting of Mr. Roberts, several of the Sanitary Commissioners of Gibraltar, and ourselves, were fortunate enough to discover a tooth and part of the jaw of a fossil elephant, which, on comparison with specimens in the Museum of Practical Geology, proved to be that of *Elephas antiquus*. On showing it to Dr. Leith Adams, he identified it as a right ultimate molar of the upper jaw (fig. 9). We believe it is the first fossil tooth of an elephant that has been found in Africa; and it is specially interesting as being of a species which was the ancestor and a mere specific variety of the living African elephant. It is well known that *Elephas antiquus* has also been found in a raised beach at Gibraltar; and in connexion with relative elevations and depressions of land with regard to the sea-level and the ancient union of Africa with Spain, this discovery is of some importance *.

Superficial Deposits, &c., of Gibraltar.

The superficial formations of the Rock present certain features which render them peculiarly interesting to the student of Pleistocene geology. They comprise massive accumulations of limestone-agglomerate, bone-breccias, deposits of calcareous sandstone, raised beaches, and loose sands. These will be described, as near as may be, in chronological order.

1. *Older Limestone-agglomerate of Buena Vista, &c.*

The oldest of all the superficial accumulations is the remarkable agglomerate or breccia which covers so large an area in the district of Buena Vista and Rosia and in the neighbourhood of the South Barracks. Similar accumulations are met with in other parts of the Rock; but these, as we shall afterwards point out, belong to a later date. In caves and fissures, as is well known, breccias also occur; but these are distinguished from the others by the presence of abundant mammalian remains. They fall to be described, therefore, under a separate heading. The breccia of which we are now about to speak is quite unfossiliferous, and appears as a distinct superficial accumulation, covering considerable areas, and resting sometimes

* [An ultimate right upper molar, with the loss of a few anterior ridges and holding fifteen plates and a posterior talon, is 8 by 3½ inches. The enamel is thick, and disks of wear well-shown, with central expansions, angulations, and crimping of the enamel. There are eleven worn disks in a space of 6¼ inches. The crown resembles the variety of *E. antiquus* to which Falconer gave the name *E. priscus*, and the disks and thick enamel are like the same parts in the molar of *E. africanus*; but the ridge-formula much exceeds that of the latter species. It belongs to the thick-plated variety of *E. antiquus* referred to in my monograph on *Elephas antiquus*, Palæontographical Society's Memoirs, 1877, p. 31.—A. L. A.]

upon the main limestone, and sometimes upon the overlying series of shales. It would be better, indeed, to restrict the term *breccia* to the true cave- and fissure-accumulations, leaving the term *agglomerate* for the great superficial masses which are at present under review. At all events this is the arrangement we shall follow to avoid confusion and obviate the necessity of frequent periphrases. The old limestone-agglomerate, then, occurs, as we have said, in greatest mass in the neighbourhood of the South Barracks, Rosia, and Buena Vista. In that area it attains a thickness in some places of not less than 100 feet, and shows occasionally a well-marked dip, as in the cliff south of the Naval Hospital, where the inclination is towards the north-east at an angle of 18°; as a rule, however, the mass is quite amorphous and devoid of stratification. The matrix is sometimes grey, sometimes reddish, and the included fragments are almost invariably quite angular, no rounded water-worn stones being visible. The agglomerate is of all degrees of coarseness, the stones varying in size from mere grit up to blocks 12 feet and more in diameter*; and larger and smaller fragments are all rudely heaped together without the slightest reference to size or shape, so as to present an appearance as tumultuous and confused as that of a coarse volcanic agglomerate.

It is a true superficial accumulation resting upon a broad irregular surface of limestone and shale, its relation to the limestone being well seen in the cliffs that overlook Camp Bay. The position of the mass is shown in Sections IV. and V. The rock-surface upon which it reposes appears to be somewhat uneven; for whereas the agglomerate merely caps the high limestone cliffs at Camp Bay, it descends below the level of the sea at Rosia Bay. From the rough and broken aspect presented by the agglomerate between the Naval Hospital and Europa Pass, Mr. Smith supposed that a land-slip had taken place there; but beyond the rugged character of the ground we could see no evidence of such a catastrophe. Indeed it seemed to us that all the appearances might quite well be due partly to subaerial and partly to submarine erosion, as we shall point out more particularly in the sequel.

As we have already mentioned, there are other masses of superficial agglomerate presenting the same general characteristics as the great accumulation at Buena Vista; but as these are clearly of later date than the latter, we shall defer description of them to another paragraph.

There can be no doubt that the limestone-agglomerates owe their origin more or less directly to subaerial forces. It is quite certain, however, that these forces are not now acting with as much vigour as at the time when the great masses of Buena Vista and Rosia were accumulated. If they were, then the formation of the agglomerate should be still continuing, which is not the case. One cannot but be struck with the appearance of great weathering which the whole mass presents. Its surface is everywhere worn and honeycombed, just like that of the main limestone itself. Nor

* Some of the larger blocks must weigh 20 or 30 tons at least.

is more than a glance needed to show that the agglomerate has been exposed for a prolonged period to the action of the weather, and that it is now, and must for a long time have been, wearing away much more rapidly than it can possibly be accreting. We need only point to the rugged aspect of the mass at Buena Vista, where the agglomerate has been excavated into gullies and ravines from 30 to 50 feet and more in depth and breadth. It will further be shown in the sequel that platforms or terraces have been cut in this rock by marine erosion, so that in every respect the Buena-Vista agglomerate bears the stamp of great antiquity.

As further proving that this agglomerate could not have originated under present conditions, we may point to the fact that the loose stones which are scattered sparingly over the surface of the limestone at the higher levels of the Rock, and which are gathered here and there into gullies by the action of the winter torrents, are not as a rule so sharply angular as the fragments in the agglomerate. More than this, it is evident that heavy accumulations of agglomerate occur, spread over wide areas, to which it is impossible that angular stones can, under present conditions, make their way from the heights of the Rock. It is quite obvious that a much greater force than that exerted by the present winter torrents was needed to bring down from the heights those large blocks of limestone that occur so plentifully in the agglomerate that stretches from the Mount down to the sea at Rosia. We were informed by Mr. Roberts and others, who have been long resident in Gibraltar, that a fall of rock from the cliffs is of the rarest possible occurrence. What the inhabitants chiefly fear are the sudden torrents of the rainy season, which now and then sweep down quantities of loose materials, grit, earth, and small stones. In short, it is evident that although stones and blocks, loosened by the action of rain and percolating water, must sometimes be launched from the higher parts of the Rock, yet the agglomerates that lie at its base and upon its flanks do not belong in the main to modern times, but owe their origin to conditions which no longer prevail.

At present frost may be said to be unknown in Gibraltar. The mean temperature of the coldest month (February) is 54°·2, and the lowest minimum reached in six years (1853–59) was 32°·7. It is very rarely, indeed, that the temperature falls so low. We were told that a thin pellicle of ice had once and again been observed upon a pail of water at the Signal Station; and Mr. Roberts informed us that there is a legend to the effect that, many years ago, ice $\frac{1}{10}$th of an inch thick had been seen at the North Front. The fact that these phenomena are specially noted at Gibraltar only serves to show how unfrequently they occur. With severe frosts in winter the inhabitants would doubtless have a lively time of it, from the frequent discharge of blocks and stones from the steep broken ground and cliffs at the foot of which the town is built. It appears to us, however, that it was precisely under such climatic conditions as these that the great agglomerates were formed. The rocks in question speak to us of strong frosts which broke up the limestone along the crest of the Rock, and showered it down in sharply-angular fragments over the precipices and cliffs. In further proof of this we may point to the frequently brecciated aspect of the limestone itself. In many places that rock looks as if it had been smashed up *in situ*, the broken fragments having been subsequently consolidated by infiltration. This appearance is especially conspicuous between Middle Hill and the Signal Station. So broken is the limestone thereabout that Mr. Smith thought this betokened the presence of a fault. But the beds may be traced continuously across the "broken" area; while further down the western slope, and precisely in the line of the supposed fault, the rock ceases to show a broken aspect. The same broken or brecciated appearance, moreover, is conspicuous in many other places in different parts of the Rock, and it is hard to see what power other than frost could have so ruptured the beds.

Of course no excessive degree of cold is necessary for the formation of rude *débris* at the base of a lofty cliff. Indeed, even under present conditions, stones and occasional larger blocks must sometimes be dislodged and rolled down the precipices; and, given sufficient time, these will gradually accumulate and become agglutinated into a breccia or agglomerate. But the old weathered and worn aspect of the agglomerates shows that these accumulations do not owe their origin to present conditions; and, as we have already indicated, the position which many of them occupy points still more strongly to the same conclusion. But something more than the mere action of strong frost is needed to account for the presence of the wide-spread and massive agglomerate of Rosia and Buena Vista. Supposing we admit that the large angular blocks with which the agglomerate is charged even down to the present water's edge were detached from the top of the limestone ridge, we have yet to explain the mode of their transportation. It is quite clear that they could not have merely rolled to their present position. A glance at Section IV. will show that from O'Hara's Tower to the Upper Road, a distance of 600 yards or so, the ground slopes at an angle of 35° as near as may be. That is not too great an angle for the repose of *débris*; and were the agglomerate at present under consideration a formation now going on, we should find it hard indeed to account for the fact that no curtain of *débris* is being formed upon that slope at present, while *the indurated* débris *or agglomerate which must have been derived from this very declivity only begins to come on in force upon the gentler slopes yielded by the shales.* Nor can we believe that the agglomerate in question originated quite in the same way as the *débris* on hill-sides in our own country. It is quite impossible to believe that large blocks and smaller fragments, even supposing they had been set in motion from the very top of the ridge at O'Hara's Tower, could yet acquire sufficient momentum to carry them across the whole breadth of the gentler slopes at the base of the Rock, a distance of 550 yards at least, over which the *average* inclination of the ground is not more than 8° or 9°*. Nor will winter torrents better account for the phenomena. No gathering of water can take place upon such a

* In some places the slope does not exceed 2° or 3°.

steep surface. The rain that does not find its way into fissures and caves rushes at once down the slopes to the low grounds. It has no opportunity of collecting into a few channels, so as to pour in one heavy torrent of depth sufficient to sweep blocks weighing several tons for a distance of about 600 yards down an incline of less than 1 in 7. Small angular fragments, indeed, and now and again larger stones (did they chance to lie in a trench or gully) might be carried away during a sudden shower of heavy rain; but it is idle to suppose that the great agglomerates which cover nearly all the districts of Rosia and Buena Vista could have originated in this way. The *cônes de déjection* formed at the base of the Rock at the mouths of the one or two gullies which at present carry occasional torrents to the low grounds are utterly unlike any of the agglomerates we are now considering. They consist chiefly of subangular stones, mostly of small size, few measuring more than 6 inches across; they are of small width and length, and do not extend outwards much beyond the foot of the steep acclivities of the Rock, and they are decidedly coarsest towards their upper limits. Moreover, in such *cônes de déjection* stratification, however rude it may be, is usually present; but in the great limestone-agglomerates not only are the stones all more or less sharply angular and arranged generally without any reference to size or figure, but the agglomerate at the foot of the Rock is not sensibly coarser than that which occurs at Rosia Bay, a distance of 500 or 600 yards away, while traces of bedding are very exceptional indeed.

Reflecting upon these and other considerations, we are led to infer that the great agglomerate of Rosia and Buena Vista is the record of a much more wintry climate than we could have imagined as likely to have characterized the Rock in recent times. We seem to have, in that agglomerate, evidence not only of the former action of frosts severe enough to wedge out large blocks of limestone, but also of more or less sudden meltings of thick snow, such as would saturate heavy trains of *débris* and cause them to move *en masse* down the steep slopes and over the lower grounds beyond. Under such conditions some portions of the *débris* could hardly fail to be partially arranged by the action of torrential waters, so as to give rise to the appearance of bedding which is noticeable here and there at Buena Vista.

The highly denuded aspect of the agglomerate implies a long lapse of time since the period of its formation. It probably at one time cloaked the lower slopes of the Rock as a more or less continuous sheet, which may have extended far up the steeper acclivities, although these are now quite bare of either *débris* or agglomerate. Shelves, terraces, and deep gullies have been excavated in the agglomerate, and it everywhere so clearly bears the marks of having suffered extreme denudation that there is no difficulty in believing that it may originally have clothed the Rock up to near the summit at O'Hara's Tower. The dip of the agglomerate at Buena Vista, which is *towards* instead of *away from* the Rock, seems to indicate that the mass thereabouts may have been undermined by water acting along the line of the main fault. A very slight sinking in of the ground along the line of that fault would account well enough for a reversal of the dip of the agglomerate, which, under any view we take of the origin of that accumulation, could only have been originally *away from* the Rock.

2. *Bone-breccias in Caves and Fissures.*

Although we visited a number of the caves, yet the object of our journey to Gibraltar did not allow us to make any special and detailed examinations, so that we have but little to add to what has already been said about the caves by previous observers. These caves are of two classes, as Mr. Busk and Dr. Falconer have pointed out, namely, 1st, those which have horizontal pavements, and which appear upon the face of old sea-cliffs; and 2nd, those that descend from the surface at various angles into the rock. The former have evidently received their present form from the action of the sea, although it is probable that in many cases they already existed before the sea got access to them. The latter, again, there can be no question, owe their origin to underground waters, their direction having been determined by the joints and fissures and bedding-planes of the limestone. Some writers have supposed that these caves, which often descend at a very high angle, sometimes approaching verticality, are merely gaping fissures formed during violent rupturing of the strata; but the faults observed by us in actual section afforded no evidence of having been left as wide, open fissures. Yet one may readily understand how such faults, by intercepting the water that descended from the surface by joints and bedding-planes, would tend to divert much of the drainage in one particular vertical direction. Faults would thus merely play the part of great master-joints, and become gradually widened by the chemical and mechanical action of subterranean water. Many of the caves, however, do not occur on lines of breakage, some of them having been excavated along lines of jointing, while others evidently coincide with planes of bedding, as, for example, those which are seen in the old sea-cliff below No. 4 Europa Advance Battery.

Often enough fissure-breccias which are now exposed at the surface appear to lie in cavities or trenches of erosion which have not always been so open to the day. In many places, again, they seem to fill up mere superficial hollows, which terminate downwards. It is from such fissure-breccias that mammalian remains appear to have been frequently obtained. Similar surface-fissures, indeed, are in process of forming and being filled up even now. This is well seen on the steep slopes above the town, where the honeycombed and weathered aspect of the limestone is very conspicuous. Rain is gradually widening the joints by dissolving out the limestone and leaving behind a red earthy residuum. Irregular-shaped fragments thus become loosened, and may fall out of place or be forced away by winter torrents, and swept, along with red earth, loose stones, and organic *débris*, into sheltered nooks and crevices, where in time all may become hardened into a solid mass by infiltration. It is worthy of note, however, that the loose stones and fragments which are found lying here and there over the surface of the rock, or gathered together into long trains of *débris* by the winter rains and torrents, are not, as a rule, so sharply angular as the bulk of the stones that occur in the unfossiliferous limestone-agglomerates.

In the caves the breccia is of a dark red colour, and appears to be made up chiefly of bones set in a matrix of red earth and hardened by calcareous matter. We saw very little of it in place, however, and cannot therefore say what proportion of limestone fragments it may contain.

In regard to the age of the caves and fissures, it is of course impossible to say in all cases how old these cavities may be; but there is indubitable evidence to show that some of them, and these the best known and most important, are of later date than the great agglomerate of Buena Vista. The famous bone-breccia at Rosia Bay, for example, clearly occupies a vertical fissure of erosion in the unfossiliferous limestone-agglomerate. From this fissure ton-loads of mammalian remains were obtained during the scarping of the cliffs, but unfortunately these have long been dispersed. To approximately the same date belongs the Genista Cave with its bone-breccia, as will be shown presently. All these caves and fissures have undoubtedly been filled by the washing into them of materials lying loose at the surface. It is evident, however, that since the time when the mammalian remains and limestone-*débris* were swept into the caves and fissures, the surface of the ground has been greatly modified. The fissure at Rosia, for example, now traverses a nearly isolated hill or craggy knoll (9th Rosia Battery); but when water flowed through it the agglomerate evidently could not have presented the same highly eroded appearance. When the bones were being conveyed into the Rosia fissure and the Genista Cave, the configuration of that part of the Rock must have differed very much from the present.

3. *Raised Beaches, Calcareous Sandstones, &c.*

The promontory of Gibraltar is marked in various places and at different levels by terraces or platforms cut into the solid rocks, and backed of course by cliffs which are more or less precipitous. Upon these platforms rest deposits of calcareous sandstone and limestone-agglomerate, which often entirely conceal the underlying horizontal or gently inclined pavements. The deposits referred to are thickest immediately under the cliffs, from the base of which they slope gradually outwards. The character of the rock-platforms, and the nature of the sandstones which lie upon them, leave one in no doubt as to the marine origin of both.

The most recent marine deposits are those which occupy the low isthmus that connects the Rock with the mainland. The surface of this plain is more or less sandy and stony; immediately underneath, however, we come upon sands which are generally pure and sharp, and contain numerous sea-shells of existing Mediterranean species. In Well No. 1, sunk by the Sanitary Commissioners of Gibraltar just within the British lines, a stratum of clay 2 feet thick was reached at a depth of 30 feet, underneath which come beds of sand which have not been sunk through. The average level of the surface is not more than 10 feet above the sea.

Mr. Smith mentions the occurrence of *Balani*, shells of *Pholades*, and clusters of mussels in a crevice exposed in a quarry at the North Front, at a height of 24 feet above the present littoral zone. We found no trace of this crevice, and the deposit has probably been removed during the quarrying operations which are constantly being carried on at that place. The same writer also refers to the occurrence of two raised beaches, one "at the height of 50 feet, and another 20 feet higher," as having been disclosed during the scarping of the ancient sea-cliff at Europa Point. From these deposits he collected upwards of 100 species of recent sea-shells; but the whole of the rock below the fortifications at Europa Point having been scarped and otherwise interfered with, the deposits mentioned by Mr. Smith are now no longer visible.

The next well-marked old sea-level is that of Europa Flats (see Section VII.), a wide plateau of bare limestone rock, forming the extreme southern portion of the promontory. From west to east it measures about 1650 feet, and 800 feet or thereabouts from the batteries to the base of the Windmill-Hill cliff. Its average elevation is about 115 feet over the present sea-level, but it slopes up from 90 feet or so to 150 feet or thereabout. The surface has been "dressed," so as to make it more even; but here and there, in hollows of the honeycombed limestone, we noticed small patches of hardened sand, made up of triturated and comminuted fragments of limestone and shells*. Mr. Smith detected in one patch in this place a valve of *Pecten maximus*. Leaving Europa Flats by the main road, we are conducted past the Governor's Cottage towards the No. 3 Europa Advance Battery along a terrace or platform of limestone which is backed by the cliffs of Windmill-Hill Flats. The surface of this terrace is buried to a considerable depth under limestone-agglomerate, but there can be no doubt that it is only a continuation of the Europa plateau. Above No. 3 Europa Advance Battery, on Monkey's-Cave Road, there is a quarry opened in calcareous sandstone, which is evidently a littoral or shallow-water deposit that rests upon the limestone terrace or shelf at present under consideration. The sandstone is usually greyish yellow or grey, but here and there

* When we remember that a very strong current sweeps past Europa Point, we need not wonder that so few traces of marine deposits should be found upon the Europa plateau; for when this plateau formed a part of the sea-bottom, there can be little doubt that it would be traversed by the same rapidly flowing water, and hence no great accumulation of detritus could take place. The sand-beds of the promontory occur only along such parts of the coast as were and still are free from the action of this strong current.

it shows a reddish tinge. It is somewhat coarse in texture, passing into a grit, and appears to be made up chiefly of comminuted fragments of limestone, quartz, and shells—none of the latter being large enough to enable us to tell the species. We noticed, however, fragments of *Echinus*-tests; and there can be no question that the deposit is a marine accumulation, similar to the shelly sand which is at present gathering here and there in shallow water along the coast. Mr. Smith, indeed, mentions that he obtained from the beds *Patella ferruginea*, a recent Mediterranean species. Beds of precisely the same character are well exposed at No. 4 Europa Advance Battery, where they dip outwards from the high cliff behind at an angle of 27° or thereabout. Just beyond the battery is an old sea-worn cave, in which the same sandstone-beds appear to form a considerable thickness, as they are piled up against the steep cliff-wall from near the present sea-level to the platform of limestone on which the battery stands, a height of 260 feet. Mr. Smith mentions the occurrence of similar deposits in and near old sea-worn caves at heights of 600 and 700 feet above the present sea-level; but these we were not fortunate enough to come upon.

The sandstone and grit evidently owe their induration to the percolation of water holding carbonate of lime in solution; and it was curious to trace in this modern rock certain appearances which have already been referred to in connexion with the main limestone. Towards the top of the sandstones, angular fragments of limestone, some of them several feet in diameter, begin to show themselves; and these can usually be distinguished at a glance from the matrix in which they lie imbedded. Now and again, however, the shelly grit or sandstone quite loses its gritty character, becoming fine-grained and almost compact; and then it so closely resembles in its lithological aspects the main limestone as to be with difficulty distinguished from the fragments of the latter, which it encloses.

It is highly probable that such sandstones and grits extend more or less continuously from No. 4 South, by Nos. 3 and 2 Europa Advance Batteries, up to and beyond the Governor's Cottage; but they are concealed under heavy masses of limestone-agglomerate, as we shall point out presently. The sandstone-beds rest upon the sea-worn platform which we have described as extending from Europa Flats past the Governor's Cottage to No. 3 Europa Advance Battery. North from that point the Europa level becomes obscured; but it doubtless continues under the agglomerate until it meets the steep cliffs that plunge down to the sea just beyond No. 4 Europa Advance Battery. There are also indications of a higher platform of limestone being concealed below the sandstone and overlying agglomerate which form the slopes that dip outwards from the base of the cliffs behind Monkey's-Cave Road. The height of the level referred to can hardly be less than 250 feet above the level of the sea. A little further to the north a well-marked platform appears excavated in the steep cliff. This old sea-margin is shown in Section IV.; it is capped, as usual, with limestone-agglomerate.

At Prince's Lines (North Front) another sea-worn shelf of limestone has been cut through by the engineering operations at the galleries, and is well seen in section. The shelf slopes gently outwards, and is covered by a thick mass of limestone-agglomerate, which also forms the slopes extending upwards to the base of the limestone cliffs above. Underneath the agglomerate occurs a thin stratum of well water-worn pebbly limestone-conglomerate. This shelf is about 150 feet or thereabout above the sea, and is most likely of the same date as the Europa Plateau. There are probably other old sea-levels concealed beneath agglomerate along the face of the Rock, both above and below Prince's Lines, the King's and Queen's Lines appearing to occupy the site of an old sea-beach, which has been scarped and otherwise modified for the purposes of defence; and doubtless low-lying old beaches might at one time have been traced along the whole western side of the promontory; but the ground has been so much built upon and otherwise tampered with that it is not possible now to map them out.

One of the best-marked sea-levels on the Rock is that of Windmill-Hill Flats (see Section VI.). This extensive plateau lies immediately north of the Europa Plateau. It measures about 830 yards in length, and has an average breadth of more than 330 yards, and its surface is 370 feet or so above the sea. Bare limestone, with a rough honeycombed surface, shows everywhere all over it, and we saw no trace of any modern marine deposits. But the plateau has been a good deal interfered with, and its inequalities removed so as to make it comparatively smooth. It is quite possible, therefore, that patches of sandstone, like those which were formerly well seen upon the Europa Flats, may also at one time have been visible on the Windmill-Hill Plateau. The plateau is cut off on all sides, save the north, by steep cliffs and precipitous slopes. In the front of these cliffs, at the height of 170 feet above the sea, there was once visible, according to Mr. Smith, an oyster-bed; "and in the same cliff, but 94 feet higher, in scarping the rock, there was discovered," he tells us, "another recent shelly deposit."

The high cliff which overlooks the Alameda Gardens (see Section III.) probably indicates an old line of coast; the slopes below it, however, are, for the most part, thickly covered with agglomerate, and so we cannot point to any marine deposits in proof of our conjecture. The base of this cliff is 500 feet above the sea.

Some reference has already been made to the fact that the great agglomerate of Buena Vista bears evident marks of having been subjected to extreme denudation. It has been eaten into, as we have seen, in the same manner as the limestone itself, and fissures and winding galleries have been licked out of it—the rugged defile that extends in a southerly direction from the top of Hospital Hill Road towards the quarry at Little Bay strongly resembling a cave the roof of which has subsequently fallen in. That this defile may have been partly eroded by the action of the sea is also very probable; and there are certain isolated pinnacles and irregular columns of agglomerate in its immediate neighbourhood which have all the appearance of being old sea-stacks. Similar stacks of the same rock may be seen even now standing out in the sea at some little distance from the shore. But the best evidence of the agglomerate having been subjected to marine erosion is afforded by a number of horizontal terraces or platforms which have been excavated in it, and which precisely resemble those that are cut in the face of the limestone-cliffs and slopes as already described.

The terraces referred to are shown in profile in Section IV. The lowest forms the New Mole Parade, and reaches 50 feet above the sea, thus corresponding in elevation to the old beach with shells that was once visible at Europa Point. The next terrace occurs behind the South Grand Store, at a height of 75 feet or thereabout, and is probably the equivalent of the 70-feet beach which Mr. Smith has recorded as rising behind the 50-feet beach at Europa. The third platform in ascending order is the flat occupied by the South Barracks, a terrace which is 330 feet in width, and rises from 120 feet or so to 140 feet above the sea. This height agrees with that of the broad Europa Plateau. From this terrace the ground rises with a somewhat rapid gradient to the fourth terrace, which forms the gentle slope near the Mount that is traversed by the Guarda Main Road. This sloping surface corresponds in elevation to the raised beach shown at the east end of the section (Section No. IV.), and to the similar platform with superimposed marine sandstone near No. 4 Europa Advance Battery. The height is 260 feet or thereabout above the sea.

Mr. Smith got recent marine deposits at a height of 700 feet above the sea; and he inferred from the worn aspect of the Rock, and the presence of caves at yet higher levels, that the whole promontory had probably been submerged within recent geological times. The caves in question, however, are not of marine origin; they are of the usual irregular character, descending to great depths and, as they are followed downwards, receiving or sending out lateral winding branches, just as is the case with limestone-caves and galleries elsewhere. From the view we obtained of the caves at the present sea-margin, immediately underneath the great cliff that descends from O'Hara's Tower, we could have little doubt that even these were not entirely the result of marine erosion, but had originated in the same way as the others, the sea having merely exposed them in the process of cutting back its cliff. The occurrence of caves, then, at a higher level than 700 feet cannot be taken as a proof of greater submergence than that. Nor is the honeycombed and worn aspect of the Rock any evidence of marine action, ordinary weathering being quite enough to account for all the appearances presented. At the same time it is of course possible that submergence may have considerably exceeded 700 feet. If it did we might expect to come upon patches of shell-bearing sandstone lying in protected crevices of the limestone, like those which were laid bare, at the time of Mr. Smith's visit, in the process of quarrying and scarping the limestone. We did not observe any, however; but a more minute search than we were able to make might be rewarded with success.

4. *Alameda Sands.*

The low ground on which the greater part of the town of Gibraltar is built consists of more or less incoherent red siliceous sand. From information supplied by Mr. E. Roberts, these deposits are indicated on the map as stretching inland as far as Engineer Lane, Governor's Street, and the Town Range Barracks. They occur all over the area occupied by the Grand Parade and the Alameda Gardens; but no good sections are now visible. Some shallow pits and holes in the Gardens showed unconsolidated red sand, with faint traces of bedding, but no marine shells. In some parts they strongly resembled the red earth which is found lying in holes and crevices in the limestone. From their position, the Alameda Sands may reasonably be inferred to be of marine origin, modified perhaps to some extent by subsequent Æolian action. They go up to a height of 160 or 170 feet.

5. *Catalan Sands, &c.*

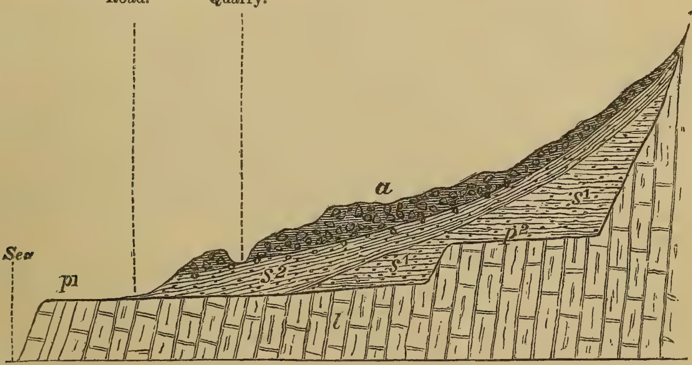
One of the most striking features of the promontory is the great bank of sand and *débris* which clothes the whole eastern flanks of the Rock from the North Front south to beyond Sandy Bay. From the base of the great cliff of Middle Hill and the Signal Station the slope sweeps down to the coast at an average angle of not less than 34°, the fall being as much as 700 feet. The slope consists in chief part of sand, with here and there scattered blocks and fragments of limestone. It is evident, however, that much limestone-agglomerate and many fallen masses of limestone underlie it. These are seen projecting above its surface here and there, especially at Catalan and south of Sandy Bay. At both these places, in fact, the sand merely lies amongst and between great blocks of limestone and masses of agglomerate and *débris*. The sand is composed of quartz granules and comminuted and worn fragments of shells, the mass being here and there partially hardened by infiltration. In such places the hardened layers stand out in relief in the same way as in the case of sandstones which have weathered unequally. Much of the sand is very coarse and gritty.

6. *Later Limestone-agglomerates.*

We pass on now to describe those masses of limestone-agglomerate which are found resting upon recent marine deposits and eroded limestone-platforms or terraces. The agglomerates now referred to are similar in most respects to the older accumulations of Buena Vista. Like them they are made up of angular fragments of limestone of all sizes, up to blocks several yards in diameter, set in a calcareous earthy matrix, which is either red or grey. In none of them, however, did we detect any trace of bedding; they are mere rude jumbled masses piled up along the base of more or less prominent cliffs, from which they slope gradually outwards.

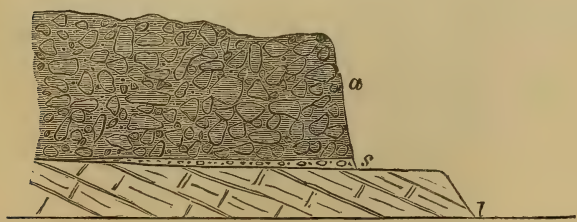
We have mentioned the fact that the calcareous sandstone and grit at Monkey's-Cave Road contains in its upper portion fragments of limestone, and that the whole deposit is overlain by a heavy mass of agglomerate. An excellent section, showing this superposition, is exposed at No. 4 Europa Advance Battery, where calcareous sandstone is seen dipping outwards from the cliff at an angle of 27°, with thick agglomerate lying directly upon it (fig. 10). At this place the sandstone did not show any included blocks of limestone. The position of this agglomerate is shown in Section No. VI.

Fig. 10.—*Section from near Windmill-Hill Barracks to the Sea near Monkey's-Cave Road.*



l. Limestone.
*p*¹. Platform of marine erosion, on the same level as Europa plateau, 160 feet above the sea.
*p*². Platform of marine erosion, on the level of No. 4 Europa Advance Battery, 260 feet above the sea.
*s*¹. Calcareous sandstone, horizontally bedded, marine.
*s*². Calcareous sandstone, dipping away from cliffs, the weathered and rearranged upper surface of *s*¹.
a. Unfossiliferous limestone-agglomerate.

Fig. 11.—*Section at Prince's Lines.*



l. Limestone. *s*. Gravelly conglomerate. *a*. Limestone-agglomerate.

At Prince's Lines another somewhat similar section is well exposed. There we see a considerable mass of red agglomerate, quite unstratified, resting upon a bench of limestone, from which it is separated to some extent by a thin layer of sand and well-rounded pebbly limestone-conglomerate. In this agglomerate, at its base, we detected some fragments of mammalian bones. The platform sloped gently outwards, as shown in the accompanying section (fig. 11).

There can be little doubt that, could we obtain vertical sections of the agglomerates which cover the flanks of the Rock in many places, similar benches and terraces with superimposed marine deposits would be found underneath them, as, for example, at the King's and Queen's Lines, and along the base of the broken cliff that extends from the Moorish Wall south towards the Mount, a cliff which is shown in profile in Section III.

The only other masses of agglomerate to be mentioned occur on the steep slopes at the North Front and at Catalan and Sandy Bays. At the North Front the slopes are composed principally of loose *débris* and sand; here and there, however, this *débris* is consolidated into agglomerate. The long steep slopes that sweep down from the Middle Hill and the Signal Station to the shore are made up in large measure of blown sand; but heavy masses of limestone-agglomerate peer above the sand, especially behind Catalan and a little south of Sandy Bay. The only rock visible along the shore between Catalan Bay and Sandy Bay is limestone-agglomerate.

Most of the agglomerates now described are certainly of more recent date than the wide-spread sheet of the same kind of rock at Buena Vista and Rosia, and possibly the same is true of all. At all events there is no perfectly conclusive evidence to show that any of them are older than the marine platforms at Europa and lower levels. They all exhibit marked appearances, however, of having been long subjected to atmospheric erosion; and the evidence in favour of their having been formed under cold climatic conditions is hardly less strong in their case than in that of the older masses at Buena Vista. It is impossible to examine the agglomerates near the Governor's Cottage, or those which overlie the calcareous sandstones at Monkey's-Cave Road, or the similar accumulations at the Prince's Lines, without being convinced that their formation must have taken place a long time ago, and that they are now no longer accreting. The great blocks and heaps of *débris* that form the agglomerate near the Governor's Cottage, and which extend outwards from the base of the Windmill-Hill plateau for 250 feet at least, can hardly owe their origin to the comparatively feeble action which the subaerial forces at present exert.

We have described certain deposits of calcareous sandstone which occur on the eastern side of the promontory. These sandstones lie close under the cliffs, and are remarkable for the presence, here and there, in their upper portions, of angular blocks of limestone. None of these blocks or fragments showed any appearance of having been rolled about in water. They seem to have been dropped into the sand when that was soft and yielding, and to have been afterwards gradually covered up. In other places, as at No. 4 Europa Advance

Battery, the sandstone contains no blocks of limestone, either angular or rounded; while in the old sea-clefts which are seen underneath that Battery angular fragments appear likewise to be absent from the horizontally-bedded sandstones which there abut against the cliffs. Immediately upon the somewhat steeply-sloping (27°) surface of the sandstones at No. 4 Europa Advance Battery comes a thick mass of agglomerate, as shown in the section (fig. 10, p. 527). It will be remembered that at Prince's Lines a similar section was laid bare, only that at that place the agglomerate was separated from the limestone platform by a thin bed of pebbly conglomerate.

From these and other like facts it may be inferred that after the limestone platforms and plateaux had been eroded, and sand and grit had been deposited upon them here and there in considerable quantities, angular blocks began to be detached from the heights above, and to plunge downward into the yielding deposits. Certain considerations would seem to render it highly probable, however, that before these blocks began to fall the sand-beds had been elevated above the sea. The sandstones which rest upon the limestone platform of No. 4 Europa Advance dip at the high angle of 27° outwards from the cliff; and all the appearances visible in that locality lead to the inference that the sandstones there form a long sloping bank underneath the agglomerate, a bank resembling the great sand-slopes of Catalan. After the sands had been lifted out of the sea, the atmospheric forces would set to work upon them, and it is not difficult to see how in no long time they would come to assume a sloping surface. Their upper portions would thus be rearranged, and the sand at and near the surface would have a dip corresponding to the steep inclination of the bank. We see precisely the same appearance of a steep outward dip in the blown sands of Catalan; and any one who shall compare the deposits of these two places will be struck with the close resemblance not only in the matter of bedding, but also in regard to their composition; for both are made up of the same coarse gritty materials. Now at Catalan some portions of the blown sand and grit are indurated by infiltration, while

Fig. 12.—*Section at Monkey's-Cave Battery,* 260 *feet above the sea.*

s. Shelly grit. *a.* Limestone-agglomerate.

in other places the accumulations are quite soft and incoherent. Stones falling from the cliffs above would plunge into the unconsolidated sand, and become drifted over and buried; while the fragments that alighted upon the hardened sand would remain in that position uncovered. Such would appear to have taken place with the calcareous sandstones in the neighbourhood of Monkey's-Cave Road. The blocks which they contain in their upper portions are quite angular, and these were probably dropped upon the yielding parts of the sand-slope and gradually drifted up; while in other places, where the sandstone contains no blocks, but is covered directly by agglomerate, we may reasonably infer that the sand had already become hardened by infiltration before the stones began to fall upon its surface. The general structure of the deposits at and near Monkey's-Cave Road is shown in the accompanying section (fig. 12).

From the evidence now adduced there can be no doubt that the limestone-agglomerates of Gibraltar belong to at least two distinct stages, the older accumulations being separated from the later masses by a considerable period of time. The Buena-Vista agglomerate was formed long anterior to the depression of the promontory, and under somewhat severe conditions of climate. The later agglomerates, on the other hand, overlie and obscure the terraces of marine erosion and the banks and beds of calcareous sandstone which rest upon these. The younger limestone-agglomerates, like the older accumulations, owe their origin to cold climatic conditions, although these were probably not so severe as during the earlier stage. The bone-breccias, again, indicate a connexion between the two continents of Europe and Africa, under mild and genial conditions of climate, while the calcareous sandstones show that these genial conditions continued during the period of depression.

Probable Succession of Events during Accumulation of Superficial Deposits.

The oldest of all the superficial accumulations of Gibraltar is undoubtedly the great limestone-agglomerate of Buena Vista and that neighbourhood. As it rests directly upon the truncated edges of the Secondary rocks, there is no evidence as to the geographical and climatic conditions that obtained before it began to accumulate. We have seen that this remarkable deposit implies the former prevalence of an extreme wintry climate, and this is still further shown by the fact that no fossil remains of any kind whatever have been detected in it. We searched narrowly the many exposures of the rock in question, but failed to meet with a trace of any thing organic; and Mr. Roberts assured us that the only fossils that were ever found within the area occupied by it occurred in fissures of precisely the same character as those that traverse the solid limestone. The best known of these fissures is that of Rosia Bay. It is seen cutting across the limestone-agglomerate in a vertical direction, and is therefore indubitably of more recent date. Enormous quantities of bones were obtained from this fissure during the operation of scarping the cliffs; and the bone-breccia may still be seen *in situ* both in the cliff and upon the beach at its base.

During the accumulation of the limestone-agglomerate it is evident that the promontory of Gibraltar must have extended considerably further seawards. This is shown by the fact that the agglomerate descends below the sea-level. But the whole appearance of the rock indicates a subaerial origin. Had the *débris*, in its unconsolidated state, pushed forward into the sea, it seems certain that the waves would have made short work with it, and rearranged its materials into more or less well-marked deposits of shingle, gravel, and sand. But one has only to look at the agglomerate to be assured that, long before the sea began to erode it, it had already become consolidated by infiltration. There can be no doubt, therefore, that the limestone-agglomerate of Buena Vista indicates a former greater extent of land at Gibraltar; but of course it is quite impossible to say how far the land then stretched out into the Mediterranean. All that the evidence entitles us to affirm is simply this:—*That the limestone-agglomerate was accumulated under somewhat severe climatic conditions, at a time when the Rock had a wider area of low ground at its base, and when, so far as we know, it was not tenanted by land animals.*

After the agglomerate had been long exposed to subaerial influences, it not only became hardened into a solid mass, but was traversed by fissures of erosion, some of which go down through its whole thickness into the underlying limestone. From the position of these fissures, and from the appearance presented by such caves as that of Genista, it is evident that both were in existence before the period of depression when the marine terraces and platforms were eroded. And not only so, but some of the fissures at least had also been choked up with bone-breccia before the great limestone-agglomerate of Buena Vista was brought under the influence of marine erosion. This is certainly the case with the celebrated bone-breccia of Rosia Bay. That fissure could only have been licked out and filled up again with bones, gravel, and earth when the surface of the ground differed greatly from the present. Since the bones and *débris* were swept into fissures and caves by superficial and engulfed torrents, that whole district has been subjected to long-continued marine erosion, by which agglomerate and limestone alike have been carved into platforms, while these terraces in turn have been greatly modified by subsequent subaerial influences. From all which it follows that the Rock was in occupation by the Pleistocene Mammalia at a time intermediate between the consolidation of the ancient unfossiliferous agglomerate on the one hand, and the formation of the limestone-terraces and raised beaches on the other.

Amongst the species obtained in the Genista Cave, and identified by Messrs. Busk and Falconer, there are rhinoceros (*Rh. hemitœchus*), horse, boar, deer (*C. elaphus* and *C. dama*), ibex, bear, wolf, *Hyœna crocuta*, lion, panther, lynx, serval, &c. At the time this fauna tenanted the Rock it is evident, as Messrs. Busk and Falconer have remarked, that Gibraltar could not have been the bare desiccated ridge that it now is. The climate was probably very genial, and vegetation must have been more abundant, so as to have afforded food for the ibex, the bones of which occur in great numbers at Genista; and several of the other vegetable-feeders were also in all probability regular denizens of the place. From the presence of the African species, Messrs. Busk and Falconer are quite justified in their inference that "there was a connexion by land, either circuitous or direct, between the two continents at no very remote period."

The next phase in the geological history of the Rock was its submergence. There is no evidence to show whether that was slowly or rapidly effected as a whole. But certain considerations would seem to lead to the inference that there were pauses in the movement, during which some at least of the limestone-ledges were eroded. It is difficult otherwise to account for the fact that certain platforms of erosion, such as that near Monkey's Cave, are covered with thick deposits of calcareous sandstone. These platforms could not surely be eroded and covered with thick sand during one and the same period of upheaval. It seems more likely that the ledge at Monkey's-Cave Road was carved out during a pause in the subsidence, and that afterwards it became buried under sand, either as the land went down or while it was coming up again, or partly at one time and partly at the other. From the presence of shells of recent Mediterranean species in the sandstone-beds, we gather that these deposits were laid down under conditions that could not have differed much, if at all, from those which are now met with in the neighbouring waters.

After reelevation had lifted these sand-beds above the level of the sea, and probably reunited the Rock to the mainland of Spain, the unconsolidated sands were exposed to the action of the weather, and gradually smoothed off into a more or less steep slope. At this time the Rock seems to have been again visited by a mammalian fauna, the remains of which occur in and underneath the more recent limestone-agglomerates that overlie the old platforms or ledges of marine erosion, as at Prince's Lines; and probably also to the same period may be assigned some portion of the cave-breccias. At the same time it is possible that the bones that occur under these beach-obscuring agglomerates may be derivative. This is a point which only future excavation will decide; at present the evidence is insufficient. It may be that the two continents were again united after the depression, and that the African Mammalia reimmigrated. In that case probably some portion of the cave-deposits may belong to this second union of the continents.

The great sand-slope at Catalan has generally been assigned exclusively to the action of the wind; and if this view be correct, then the slope must date its origin to a time when a wide tract of low ground existed to the east and north-east of the promontory. The sand (which contains much quartz) cannot possibly have been derived from the degradation of the limestone series of Gibraltar, but, no doubt, results from the waste of coarse sandstones like those of the Queen of Spain's Chair and that neighbourhood. There can be little question that these sandstones are continued out from Spain into the Mediterranean to the east of Gibraltar. It is quite possible, therefore, that the sands of Catalan may have been drifted into their present position by the winds at a time when a low-lying country with an exposed sandy beach existed to the east and north-east of the promontory. On the other hand the sands of Catalan so closely resemble the hardened sands (calcareous sandstone) of Monkey's Cave, &c., as to render it quite probable that they may have had a similar origin. They may merely indicate, as Mr. Maw has suggested, the presence of marine deposits which have been top-dressed, as it were, and obscured by the subsequent action of wind and weather. Were they to become indurated and buried underneath agglomerate they would present precisely the same appearance as the calcareous sandstones of Monkey's-Cave Road and that neighbourhood. Be that as it may, however, there can be no question that the present slope is of comparatively recent origin, and that the sands overlie massive agglomerate which is seen cropping out all along the sea-coast.

It was probably during the last considerable elevation of the promontory that the later limestone-agglomerates were formed. The winters were considerably more severe then than now, so that frost broke up the limestone on the ridges and exposed declivities, and showered *débris* and blocks in great abundance upon the sand-slopes at Monkey's-Cave Road and upon the raised beaches all round the Rock.

Then ensued the final movement of depression, which resulted in the present outline of the Spanish coast. It is quite possible, however, that this movement may have carried the land down to a lower level than the present, and that the present position of the Rock may be due to a subsequent upheaval of no great amount, the raised flat that connects the Rock with Spain being perhaps the indication of this latest movement. But there is nothing in the evidence that would seem to make such a supposition necessary. All the facts appear to meet with a simple explanation without it. We have therefore the following stages represented by the Posttertiary deposits at Gibraltar:—

1. *Great unfossiliferous limestone-agglomerate of Buena Vista, &c.*—Land of greater extent than now; winters very cold; Gibraltar apparently not tenanted by the Quaternary Mammalia.

2. *Caves and fissures with bone-breccia.*—Land of greater extent than now; Europe and Africa united; climate genial; immigration of the African Mammalia.

3. *Platforms or terraces of marine erosion (in part), calcareous sands, &c.*—Depression of the land to the extent of 700 feet below present level; movement interrupted by pauses of longer or shorter duration; climate apparently much the same as now.

4. *Platforms of marine erosion (in part); Alameda Sands; formation of sand-slopes on east coast, as at Monkey's Cave; mammalian remains under beach-obscuring or later limestone-agglomerate*

(*perhaps cave-deposits in part*).—Reelevation; land of greater extent than now (Africa and Europe perhaps reunited); climate probably genial.

5. *Later limestone-agglomerates resting upon and obscuring erosion-terraces and sand-slopes, &c.*—Geographical conditions probably same as during part of 4; winter considerably more severe than now.

6. *The present.*—Characterized by the absence of the action of frost.

Concluding Remarks.

Cause of the cold conditions that gave rise to the formation of the great Limestone-agglomerates.

At first sight there would seem to be little difficulty in accounting for the cold conditions of climate that obtained at the Rock during the accumulation of the great agglomerates. Knowing that Europe and Africa must have been united in Quaternary times so as to allow of the immigration into our Continent of the African Mammalia, one is apt to conclude that when this union existed the Rock of Gibraltar might have reared its head to such an extent as to bring it under the influence of sharp frosts. We do not know, however, whether the two continents were connected at the time the great agglomerates in question were accumulated. All the evidence goes to show that the Pleistocene Mammalia did not make their appearance in Gibraltar until long after the formation of the older agglomerates of Buena Vista. Of course it is quite possible, and even probable, that they entered Europe before that; but, if so, there is no trace of that early immigration to be detected in the superficial deposits of Gibraltar, the evidence must be sought for elsewhere.

If, therefore, we attribute the formation of the older unfossiliferous agglomerates to a former greater elevation of the Rock, we of course indulge in a mere guess, since it is quite impossible to show that the Rock was then much more than one or two hundred feet higher than it is now. Besides, the height to which it would be necessary to elevate the Rock to bring about the required climatic conditions is such as to make it extremely improbable that an elevation of the land was the cause of the cold.

A comparison of the present monthly mean temperatures of Gibraltar with those that would obtain were the height of the Rock to be increased by 1000 feet or so, will show that Europe and Africa might have been connected across the Straits of Gibraltar so as to allow of the immigration of the African Mammalia without Gibraltar having been subjected to severe winters. To the kindness of Mr. Buchan, of the Scottish Meteorological Society, we are indebted for the following Table, which shows the mean and minimum temperatures, on the average of ten years (1853–59 and 1864–68), at a height of about 48 feet.

	Mean.	Minimum during six years, 1853–59.
January..	54·7	37·9
February	54·2	35·3
March ..	56·8	41·2
April	61·5	47·9
May	65·7	49·3
June	71·0	48·6
July	74·9	60·8
August ..	75·5	61·5
September	72·4	55·9
October ..	65·6	50·9
November	60·7	44·6
December	56·2	32·7, lowest minimum in six years.
Year	64·1	

It will be observed that the coldest month of the year is February, which has a mean temperature of 54°·2. Mr. Buchan remarks that an increase of 1000 feet to the height would lower the monthly means about 3°, so that we may take the mean temperature of February at the top of the Rock (1396 feet) to be in round numbers 50°. Let us now add another 500 feet to the height, so as to give an altitude of, say, 1900 feet. An elevation to this extent would restore the land-passage by which the southern Mammalia may have entered Spain, but it would be quite inadequate to bring about climatic conditions sufficient to account for the formation of the great limestone-agglomerate. In point of fact it would reduce the mean temperature of the coldest month by only 4° or 5°, thus giving a *winter mean* of, say, 45° at the top of the Rock. Under such conditions, the minimum temperature of 32° would no doubt be reached more frequently than it is at present. But it is hardly necessary to say that this would be altogether insufficient to induce the formation of agglomerates like that of Buena Vista. To wedge-out blocks measuring 12 feet and more across, and to form thick masses of angular *débris,* we need a frost capable of penetrating to some considerable depth; and, more than this, we require the agency of heavy snows, the melting of which shall saturate the *débris*-heaps so as to cause them to flow *en masse* for more than 500 yards over a gently inclined surface; and since much of the agglomerate has been formed by the splitting-up of the limestone at levels which are now raised only some 300 feet or so above the sea, it follows that a mean winter temperature not above the freezing-point must have obtained even at these comparatively low levels. But before such a temperature could be experienced now at Windmill Hill and Europa, we should require the whole Rock to be upheaved for 6000 or 7000 feet. Surely we can hardly suppose it possible that the Rock stood some 7000 or 8000 feet above the sea-level of Pleistocene times! And if such a degree of elevation be necessary to account for the phenomena of the massive limestone-agglomerates, then it is extremely improbable that the refrigeration which produced these accumulations could have been brought about by the former greater elevation of the land.

But it may be said that an elevation of as much as 7000 feet would not be necessary if, as some geologists believe, the Sahara happened to be submerged during the Pleistocene period. But, supposing such submergence to have actually taken place in Pleistocene times, what evidence is there to show that the drowning of the Sahara coincided in point of time with the formation of the unfossiliferous agglomerates of Gibraltar, or, for that matter, with the appearance of land-passages across the Mediterranean? It is certain that a movement of depression occurred during the formation of the Posttertiary deposits of Gibraltar, by which the Rock was carried down 700 feet below its present level, the actual amount of depression being probably not less than 2200 feet, for the two continents were certainly connected in times immediately preceding that depression. Again, a subsequent movement of elevation lifted the Rock considerably above its present level, and may even have restored the connexion of the continents; and it is certainly not unreasonable to infer that these movements of depression and elevation may have extended southward, so as to influence the level of the Sahara. When a land-passage existed between Spain and Barbary, the region of the Sahara may likewise have been relatively higher than now; and, again, when the shell-beds of Gibraltar were being formed, the sea may also have covered all the low-lying tracts of the Sahara. But, as we have seen, the raised beaches of the Rock contain shells of living Mediterranean species, so that climatic conditions during the depression were certainly not colder than at present.

To what extent the Sahara may have been depressed in Pleistocene times we have no certain evidence to show. From the presence of certain deposits at a height of 2000 feet south of the Tell plateau, as described by Mr. Maw, and supposed by him to be marine, Mr. Dawkins has inferred that the Pleistocene submergence may have reached to that extent at least. Unfortunately, however, the deposits in question appear to be unfossiliferous, and we cannot be sure, therefore, whether they are even marine. And if they really be marine they are more likely to be of Newer Pliocene than Pleistocene age; for while we have no evidence in the Mediterranean area of any great Pleistocene depression, we have the most abundant proof of a very great submergence in Newer Pliocene times. The chances, therefore, are much in favour of any high-level marine deposits of apparently recent formation that may be found bordering the Sahara being of Newer Pliocene age. Be that, however, as it may, there is nothing in the evidence that would lead us to suppose that a great Pleistocene depression of the Sahara and Northern Africa coincided in time with a considerable elevation of the Mediterranean area. On the contrary, it seems more reasonable to infer that, if the Sahara was really under water in Pleistocene times, this submergence was probably contemporaneous with the greatest depression ever experienced at Gibraltar. For the sake of argument, however, let it be admitted that a Sahara sea was actually contemporaneous with the existence of land-passages between Europe and Africa, and then let us inquire what effect such a sea under these conditions would have upon the climate of Europe.

At present the prevalent winds in the Mediterranean are northerly, and this is due in chief measure to the influence of the desert. The superheated sands exercise, as M. Martins remarks, a thermometric aspiration from the north towards the south. Even in winter, although the winds of the Mediterranean are somewhat variable, yet northerly currents still predominate, for the simple reason that the atmospheric pressure is lower in Africa than in Central and Southern Europe. In the Straits of Gibraltar the prevalent winds are westerly and easterly. This is seen in the following Table, given by Prof. Coffin in his elaborate treatise in the 'Smithsonian Contributions to Science'* :—

Time of the year.	Relative prevalence of winds from the different points of the compass.									Direction of Resultant.	Ratio of Resultant to sum of winds.
	North.	N.E., or between N. and E.	East.	S.E., or between S. and E.	South.	S.W., or between S. and W.	West.	N.W., or between N. and W.	Calm or variable.		
January...	1	2	7	4	2	3	5	7			
February	1	0	6	2	1	5	4	9			
March ...	1	1	6	2	2	8	3	8			
April	0	1	3	4	1	6	3	12			
May	0	0	5	4	1	8	3	10			
June	0	1	8	5	1	8	3	4			
July	0	1	11	4	2	3	5	5			
August ...	1	1	10	4	1	4	4	6			
September	1	1	9	3	0	3	5	8			
October ...	1	2	9	3	1	6	3	6			
November	1	2	9	3	1	3	4	7			
December	1	2	6	3	2	3	1	13			
Spring ...	1	2	14	10	4	22	9	30	...	S. 82° 39′ W.	·26
Summer...	1	3	29	13	4	15	12	15	...	S. 81° 55′ E.	·11
Autumn...	3	5	27	9	2	12	12	21	...	N. 20° 19′ E.	·05
Winter ...	3	4	19	9	5	11	10	29	...	N. 54° 28′ W.	·14
The Year	8	14	89	41	15	60	43	95	...	S. 86° 59′ W.	·07

It is pretty clear, then, that the present climate of Gibraltar is affected to only a small extent by the presence of the great Sahara desert to the south. The only winds experienced at the Rock which seem to have come from the heated sands of Northern Africa are those that blow from a south-easterly quarter. This south-east wind, or "Levanter," is a variety of the Sirocco. It is hot and often loaded with impalpable dust; at Gibraltar, while it blows, a

* Vol. xx. p. 439.

thick cloud of vapour envelops the Rock. Gibraltar lies so near the Atlantic, however, that its general summer temperature is not greater than that of places situated considerably further to the north, as Madrid, Barcelona, Perpignan, Montpellier, &c.; but in winter the mean temperature of the Rock is some 9° higher than at these places. It is evident, indeed, that the proximity of the Atlantic exercises a predominant influence upon the temperature, giving to Gibraltar a kind of insular climate.

Now, if the Sahara were submerged, it is certain that the Solano or Levanter would cease to blow, and the temperature in the western basin of the Mediterranean would be reduced in summer, but the change of temperature at Gibraltar would be very small. We have seen that an elevation of the Rock for 1500 feet or so would lower the temperature only 4° or 5°; and even this slight reduction would probably be lessened by the influence of the physical conditions that would obtain upon a general elevation of the Mediterranean area for 1500 feet or thereabout. We must remember that such a degree of elevation would convert the Mediterranean into two salt lakes, the eastern one of which would receive the drainage of several great rivers, while the western basin would be supplied by no river larger than the Rhone. In this latter basin, therefore, evaporation being much greater than the influx of fresh water, the level of the inland sea would be gradually lowered, and the area of land increased, so that in course of time the western lake might be reduced to very moderate proportions, and this would of course tend to increase the summer temperature along its borders. Thus any lowering of summer temperature that might take place at Gibraltar, owing to the elevation of the land and the influence of the Sahara Sea, would gradually be lessened as the western salt lake continued to contract.

In winter no dry winds would come from the Sahara, all the southerly winds would be warm but moist; and we may easily believe, therefore, that the glaciers on the south side of the Alps would increase to some extent, so as perhaps to rival in importance the Swiss glaciers of to-day. We can hardly suppose, however, that the winter temperature of Gibraltar would be reduced. There would not be the same powerful radiation as now in the Sahara region; but the sea spread over that area, retaining its high temperature for a longer period, might be expected to increase the warmth of the Mediterranean area; for, as Mr. Buchan remarks, the submergence of the Sahara "would bring about a marked diminution of aerial and oceanic currents *from the north* over and off the north-west of Africa." It is with the winter climate of Gibraltar, however, that we are principally concerned, and not with that of the whole Mediterranean area. And it seems impossible to doubt that, even under the physical conditions supposed, the winter temperature at the Rock would remain much as it is now. The rainfall would probably be greater, but the proximity of the Atlantic would tend then, as now, to prevent any extreme winter climate.

From these and other foregoing considerations it seems most reasonable to conclude that the former cold conditions to which the Gibraltar limestone-agglomerates testify could not have been due either to an elevation of the Mediterranean area, or to a submergence of the Sahara, or to both of these combined. We appear, therefore, shut up to the belief, as the most probable explanation of the phenomena described in this paper, that the cold conditions referred to were contemporaneous with that general refrigeration which took place over so vast an area in our hemisphere during the Pleistocene or Quaternary period. When we remember that large glaciers existed then, not only in the Sierra Nevada, but in the Atlas, the Lebanon, and in Anatolia, while at the same time the glaciers of the Caucasus and the Alps greatly exceeded their present dimensions, and when we also bear in mind the enormous development of glacier-ice that took place in all the mountainous districts and northern countries of Europe, it is impossible to believe that the south of Spain could have escaped the influence of a refrigeration so great and general. In the light of all these facts, it ceases to be surprising that the Rock of Gibraltar (which, during Pleistocene times, may have stood 1500 or 2000 feet higher) should afford evidence of having at some comparatively recent period passed through colder conditions of climate than it now enjoys. Nor is it uninteresting to observe that just as in the Glacial deposits of Central and Northern Europe (not to mention those of Northern America) we have proofs of former great alternations of cold and genial climates, so in the superficial accumulations of Gibraltar we have evidence of similar vicissitudes—conditions extremely favourable to the formation of coarse agglomerates having occurred at least twice, while the climatic conditions of the intervening period apparently did not differ much, if at all, from those which are at present characteristic of the Straits.

EXPLANATION OF PLATE XXIII.

Geological map of Gibraltar, on a scale of two inches to one mile.

Discussion.

Prof. T. Rupert Jones congratulated the Society on hearing Prof. Ramsay's communication, which he characterized as a typical paper, bringing modern knowledge to bear upon and illustrate earlier researches. Before asking for further information upon some points, he would state his objection to the word "agglomerate," which was intended by Lyell to be applied to a volcanic rock, being used by the authors for limestone-breccias. Prof. Jones asked Prof. Ramsay for further information as to the cause of the great differences of dip in the several sections of the rock, differences incompatible with north and south undulations of the strata and referred by Mr. James Smith to a succession of transverse faults from the truncated northern escarpment to the Straits. With these faults, he thought, the caves explored by Capt. Broome and others were connected, and on these the authors had made no remarks. Prof. Jones had also hoped for some information as to the continuation of this remarkable isolated mass of inclined strata to the hills of Spain and of Morocco; and he stated that some very large delicate *Terebratulæ*, different from those exhibited, had been found in old Moorish building-materials from local Tertiary soft limestone, the place of which it was desirable to know.

Prof. W. Boyd Dawkins urged that, as the land was more elevated when the breccias were formed, at least to the extent of the depth of the existing Straits, Gibraltar would then have been raised some 1800 feet above its present level, which would bring the highest summit of the rock to an elevation of about 3200 feet. Mr. Maw had described glaciers in the Atlas Mountains descending to about 5000 feet. As ice was not wholly unknown on the Rock of Gibraltar at present, he thought that the difference of elevation would account for sufficiently severe frosts to produce the angular débris, supposing their production to be due to this agent. Even at the present day snow descended to between 2000 and 3000 feet above the sea near Naples. Increased elevation alone, he thought, might account for the formations of these breccias. With regard to the fossils obtained, he remarked that among them there were no traces of Arctic mammals, which are known to extend as far south as the Pyrenees, the Mediterranean, and the Alps, but no further. *Elephas meridionalis* had already been found in Africa, but this was the first time that *E. antiquus* had been obtained there.

Admiral Spratt remarked that to the westward of Tarifa Point there exists a submarine ridge the depth of which nowhere seems to exceed 120 or 130 fathoms. An upheaval of about 800 feet would therefore connect the two continents by dry land at this point.

Mr. Charlesworth said that he presumed it was not solely upon the evidence of the *Rhynchonella*, which had been identified with *Rh. concinna*, that the authors founded their ascription of the limestone to the Jurassic series. He thought that if the specimen were shown to half a dozen palæontologists experienced in the study of the Brachiopoda, half a dozen different opinions might be obtained as to its specific identity.

Mr. Ussher compared the limestone-agglomerate with the "head" of the Cornish coast, which he had accounted for by a greater elevation of land attended by a sufficiently rigorous climate to produce extensive weathering of exposed rock-surfaces.

Mr. John Evans inquired whether the authors had been able to detect any submerged terraces of denudation in the sea immediately surrounding Gibraltar; and also whether it was not possible that the two breccias described were of the same age, seeing that they were not superposed.

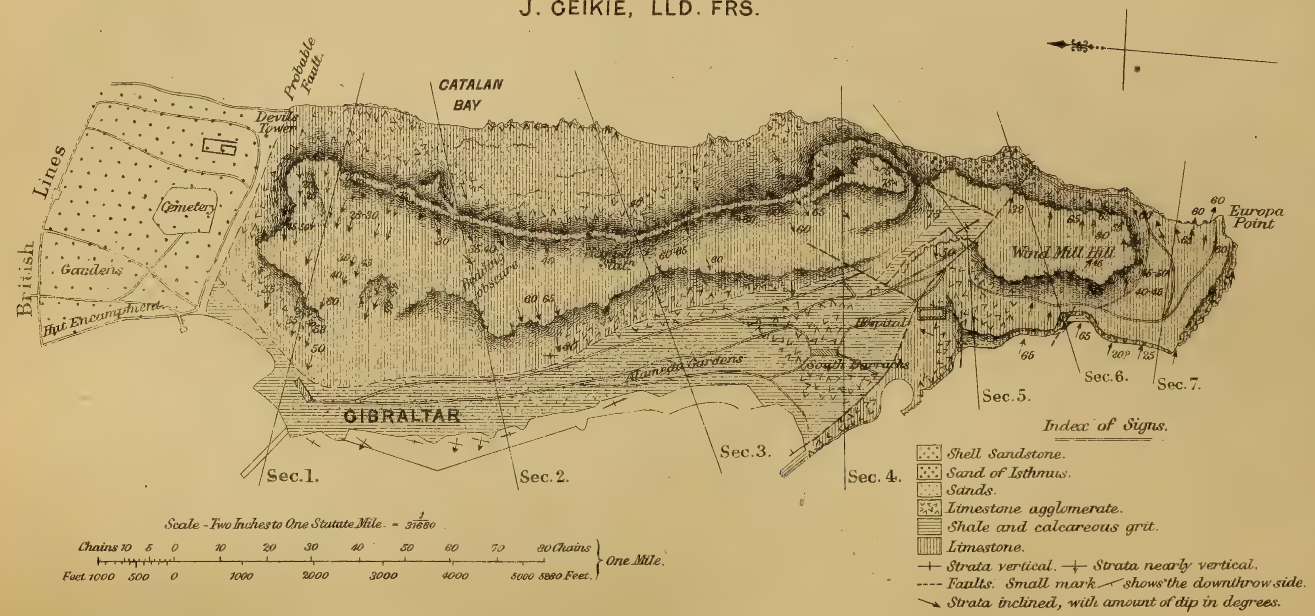
Mr. Whitaker inquired whether the authors had investigated the origin of the cliff on the west.

Prof. Hughes maintained that the increase in the height of the rock would suffice to account for the production of the breccia. He asked whether the caves implied any difference in the configuration of the land.

GEOLOGICAL MAP OF GIBRALTAR.

BY

A. C. RAMSAY, LLD. FRS.
AND
J. GEIKIE, LLD. FRS.



DANGERFIELD. LITH. 22, BEDFORD ST. COVENT GARDEN.

Prof. Ramsay, in reply, said that frost was a most exceptional thing in Gibraltar, and that snow was absolutely unknown. He indicated that some agent was necessary for transporting the blocks from the foot of the steep slopes along the gentle slopes at angles of 2° or 3°. The caverns were like all other limestone caverns, and had no necessary connexion with the faults. All the faults were noted in the paper. Mr. Smith's supposed fault had no existence. The *Terebratulæ* mentioned by Prof. Jones came from the Spanish side, not from Gibraltar. With regard to the identification of the *Rhynchonella*, he said that, having submitted it to Mr. Davidson, he was content to accept that gentleman's determination. In reply to Mr. Evans he said that he had no opportunity of examining the soundings.

34. Notes *on the* Geology *of* Japan. By J. G. H. Godfrey, Esq., F.G.S., late Mining Engineer-in-Chief to the Japanese Government. (Read March 6, 1878.)

One of the first published accounts of the geology of Japan is contained in the paper read by Baron von Richthofen before the Geological Society of Berlin in 1873.

That author stated his belief that the backbone of the Japanese islands was formed by three systems of mountain-ranges composed chiefly of Silurian and Devonian strata accompanied by granite. The first and main system, of which the axis trends from W. 30° S. to E. 30° N., extends through the island of Kiushiu, and afterwards continues up to the great bend in Nippon, the largest island of the group. This first system is intersected at either end by another which runs S.S.W. to N.N.E. On the west it commences in Kiushiu and extends southward in the direction of the Liukiu Islands, whilst on the east it constitutes the northern branch of the main island, and with a slight deviation in its course continues through the islands of Yesso and Saghalien. A third system, not properly belonging to Japan, is indicated by the S.W. and N.E. line of the Kuril Islands. The first system, where it occupies the country for itself alone, is comparatively free from volcanoes; the second is accompanied by volcanoes; but the greatest accumulation of volcanic rocks as well as extinct volcanoes is found in the places of intersection, or those regions where the lines of two systems cross each other, and also in that region where the third system branches off from the second.

Amongst the details regarding the volcanoes of Satsuma, particular attention was drawn to the fact that the various families of volcanic rocks appeared there at the surface in exactly the same order of succession as is the case in Hungary, Mexico, and other volcanic regions, viz. :—

1. Propylite or trachytic greenstone.
2. Andesite.
3. Trachyte and Rhyolite.
4. Basaltic rocks.

Within the last few years a careful geological survey has been made of the northernmost island Yesso, under the direction of B. S. Lyman*, who divides the rocks of Yesso into seven different groups :—

1. New alluvium.
2. Old alluvium.
3. New volcanic rocks.
4. Toshibets group.
5. Old volcanic rocks.
6. Horimui or coal-bearing group.
7. Kamaikotan or metamorphic group.

* B. S. Lyman, 'General Report on the Geology of Yesso:' Tokio, 1877.


GEOLOGICAL SKETCH
MAP OF JAPAN.
Index.
New & Old Alluvium
Toshibetsu
New Volcanic
Horimui
Old Volcanic
Metamorphic
YESSO
NIPPON
KIUSHIU
Shikoku
COREA
Sado
Kuchi
Heigori
Sendai
Skegawa
Hirado I.
East of Greenwich
128°
132°
134°
144°
146°
148°

This division of rocks is also applicable to the remaining islands of Japan, as according to my experience they are undoubtedly of a geological construction similar to that of Yesso (see Map, p. 543). No proper geological survey of these latter islands has been yet made, and consequently no statement as regards the probable thickness of these groups of rocks can be given.

1. *New alluvium* (under which is to be understood the detritus at the present time conveyed from the surface of the hills to the level lands below) is to be found in most places close to the sea-shore, and chiefly in the eastern portion of the main island. The most fertile plains of Japan, as those of Tokei and Kioto, belong to this formation.

The three mountain-ranges form the centre lines and at the same time also the watersheds of the Japanese islands, and consequently most of the rivers have only a short course and descend rapidly towards the coast. Owing to this circumstance and also to the comparatively rapid disintegration of the rocks in general, nearly all the rivers in Japan have a tendency to silt up. To prevent inundations, the river-beds are often by artificial means kept at a considerably higher level than the surrounding country. This explains also why Japan, though well provided with running water, is poor as regards rivers navigable for larger vessels than the usual small flat-bottomed craft of the country.

Sand of magnetic iron-ore, undoubtedly derived from the adjoining volcanic and metamorphic rocks, is frequently met with along the sea-shore and largely used for manufacturing an excellent quality of iron, as, for instance, at Nakayama, province Gueshiu.

Most of the river-sands, and chiefly those of the northern part of Nippon, contain grains of metallic gold; but it was only in former times, when wages were considerably lower than at present, that these sands paid for washing. River-sands of a better quality are occasionally worked by farmers in the province of Koshiu during the quiet season.

2. *Old alluvium* comprises the deposits of ancient rivers. Usually the various beds are level or nearly so, and are often washed out by the present rivers in their course towards the sea. Sometimes, as in the neighbourhood of Yokohama, terraces are observed near the sea-shore which appear to be due to the repeated raising up of the beach by volcanic action. Careful observations could not detect any proofs of glacial action in the old alluvium; and consequently it appears to be doubtful if such can be referred to the same age as the drift or diluvium.

Owing to their formation, the lands belonging in age to the old alluvium are usually situated at a higher level; but at the same time they are of large extent, and almost equal in fertility to the lower-lying ground of the new alluvium. As regards useful minerals, gold and iron-sand are occasionally met with to a limited extent, and their mode of occurrence is precisely the same as that previously mentioned under the new alluvium.

3. *New Volcanic Rocks.*—These rocks, represented by basalt, tra-

chyte, and pumice, form a great portion of the island of Nippon, but are less predominant in the islands of Shikoku and Kiushiu. Large and extensive accumulations of a decomposed trachytic rock, often 300 feet and more in thickness, can be seen in the northern part of Japan in the neighbourhood of Murioka. Almost all the volcanoes of Japan are extinct; but a few, like Asamoyama, emit continuously a dense sulphurous smoke, and occasionally eject ashes and pumice. Sometimes a sudden outburst is recorded of a supposed extinct volcano, as happened in the beginning of last year with that situate on Vries Island, close to Yokohama. The island of Nippon, and chiefly the neighbourhood of Fusiyama, is subject to frequent earthquakes of more or less violence; during the year 1876, a large tract of beach was elevated sufficiently to become dry land and available for cultivation in the Miyeken, the S.W. part of Nippon.

Hot springs in close connexion with new volcanic rocks are very numerous in Japan. Extensive deposits of sulphur are found upon the craters of old extinct volcanoes.

4. *Toshibets group.*—This group of rocks consists of alternating layers of sandstone, clay, and conglomerate, and is largely represented in the provinces of Echigo and Shinano. These rocks contain petroleum and fibrous lignite. The latter, however, is sometimes closely associated with black shining coal; and therefore it appears to be highly probable that this and the older Horimui, or coal-bearing group, occasionally pass into each other. The fossils found in the Toshibets group of rocks lead to the belief that they belong to the Middle or Lower Tertiary formation.

5. *Old Volcanic Rocks.*—A considerable portion of all the islands belonging to Japan appears to be made up of this group of rocks. They often appear distinctly bedded, and have then a gentle but considerably varying dip. The rock of most frequent occurrence is a trachytic porphyry or rhyolite.

A rhyolite of a light-green colour, which consists of a very fine compact but not vitreous felspathic matrix enclosing small grains of oligoclase, and sometimes small fragments of the same rock, is the rock which contains most of the valuable metalliferous deposits in Japan. As a rule, close to the contact between the deposit and the rhyolite, the latter is impregnated with numerous fine grains and sometimes well-defined small crystals of yellow iron-pyrites.

A dark-green variety of rhyolite, showing larger grains of oligoclase, quartz, and fragments of the same rock imbedded in a compact felspathic matrix, is usually found barren of ore-bearing veins or deposits.

Numerous lodes and deposits containing gold, silver, copper, lead, and blende are found in the rhyolitic formation, and in several instances they are cut off by dykes of basalt or dolerite. As a general rule these lodes or deposits are of rather limited extent; but some of them, as the quartz veins of Sado (prov. Sado), Ikuno (prov. Tajima), and Innai (prov. Uzen), are of considerable size, continue to great depths, and have proved productive for a considerable number of years. In some parts of Japan, as, for instance, in the lead-and-copper district of Ani (prov. Ugo), the rhyolite has become soft by decomposition, and in consequence a number of thin veins can be worked profitably. Propylite and andesite are of rare occurrence. The first is the containing-rock of some of the gold-mines in the province of Satsuma (Serigano); the latter is traversed by some inferior copper-veins in the province of Tajima.

6. *Horimui or Coal-bearing group.*—This group of rocks appears to be best developed in the western part of Japan, and there in the northern part of the island of Kiushiu. Coal-bearing beds of considerable extent have also been disclosed on the eastern coast of the main island; but here the coals are decidedly of more recent age than those of Kiushiu, which, according to their fossils, belong to the Cretaceous period.

The coals occurring on the eastern coast are lignite, often showing the structure of wood; but those found in the western part of Japan approach in their character and appearance the real coal of the Carboniferous formation. In the present state of our knowledge it is impossible even roughly to assign the area of this coal-bearing formation in Japan; but it is certainly of considerable extent; the area of the principal coal-fields in the western part of Japan has been estimated by me at about 270 square miles (Plunkett's Report on the Mines of Japan, April 22nd, 1875, p. 7).

7. *Kamaikotan or Metamorphic group.*—The rocks belonging to this group appear to form the backbone of the various islands composing Japan. They are distinctly stratified and usually have a very steep dip of 60° and more; and they are represented by clay-slate, sometimes changing into talcose-slate, mica-schist (chiefly in the island of Shikoku), chloritic schist, serpentine, and crystalline limestone. In some parts of the country a dark-coloured quartzite appears to be bedded with the clay-slate. Owing to the absence of any distinct fossils, the probable age of this group of rocks is yet unsettled. Von Richthofen considers them Devonian or Silurian; but up to the present time no decided proof has been adduced in support of this view. A trilobite belonging to the genus *Asaphus* was shown to me during my travels in the northern part of Nippon; but I did not succeed in finding anywhere a similar specimen *in situ.* Intruded granite and diorite occur frequently in connexion with the metamorphic rocks. On the whole the metamorphic rocks are poor in useful minerals, although some of the most important copper-lodes in the northern part of Nippon continue their course undisturbed from the old volcanic rocks into the adjoining metamorphic slates; and in a few other localities deposits of considerable importance appear to belong entirely to this group of rocks. At Handa (prov. Iwashiro) a large deposit of silver-ore occurs in mica-schist close to its junction with granite; and in the island of Shikoku a large and well-defined copper-lode is found in clay-slate and mica-schist interstratified with serpentine and quartzite. The magnetic iron-ore deposits of Heigori (prov. Rikuchu) are associated partly with felsite and felspathic porphyry, and partly with dioritic rocks; sometimes they even come into contact with crystalline limestone. The mode of occurrence leads to the belief

that these deposits have to be reckoned under the group of metamorphic rocks.

Some of the crystalline limestone may be considered useful for ornamental purposes.

Useful Minerals.—Amongst the useful minerals of Japan are to be mentioned, according to their importance, coal, copper, silver, gold, iron, petroleum, lead, and tin. Of minor importance are sulphur, antimony, quicksilver, kaolin, and salt.

(*a*) *Coal.*—Under this heading we may distinguish brown coal, fibrous and earthy, and black coal, caking and non-caking.

The seams of fibrous and earthy brown coal occurring in the Toshibets group of rocks are generally of such limited extent and their quality is so inferior as not to deserve much notice. Next in quality come the coal-deposits along the eastern coast of Nippon, which begin at Skegawa (prov. Iwashiro) and extend in a belt of 7½ miles width about 30 miles to the north. With occasional interruptions, these coal-deposits appear to continue yet for a considerable distance (about 200 miles) northwards. The following section has been observed in this district:—

Clay and sand	15 to 20 feet.
Coal	6 to 9 ,,
Hard bluish clay	9 feet.
Coal	1 foot.
Hard bluish-grey clay	8 feet.
Coal	1 foot.

The coal is black and shining, but only the first seam has been worked, and of this usually from one third to one half is left underground on account of its being too ashy. Owing to the inferior quality of the coal raised, the working of this deposit has been almost entirely abandoned.

Towards the north at Kuchi, in the province of Rikuchu, the coal-seams have been found to contain a considerable amount of a dark-coloured amber, which is used for ornaments.

The most important coal-fields are situated in the *Horimui* formation of the western part of Japan, where the coals assume the character of Carboniferous coal, and most of them are more or less caking.

The islands in the neighbourhood of Nagasaki, and amongst them prominently Takasima, furnish the best coal yet discovered in Japan; Takasima coal, as regards its use for steamers, has been proved to be only slightly (about 10 per cent.) inferior to the best Cardiff coals.

By far the greatest portion of this coal-formation is now covered by the sea, and it is only on these islands that the coal-seams have been upheaved and can be worked.

The following are sections of the coal-bearing strata at Takasima, Mieke, and Karatsu (the Mieke coal-mines are situated nearly due east, and those of Karatsu to the north of Takasima):—

Takasima (island).

General dip N.W., 12° to 18°.

130 feet sandstone intermixed with clay.
30 feet bind.
8 feet seam .... { 6 inches shale. / 3 inches fire-clay. / 6 inches clay. / 7 feet coal. }
68 feet sandstone.
Stony coal ...... { 1 foot bind. / 8 inches bitum. shale. / 2 feet bind. }
25 feet 11 inches alternations of bind, sandstone, and ironstone.
19 feet 6 inches sandstone.
1 foot seam......... { 1 foot 8 inches shale. / 10 inches coal. / 7 inches shale. }
9 inches coal.
2 feet 6 inches black shale.
2 feet 6 inches shale and ironstone.
42 feet sandstone.
1 foot 7 inches grey bind.
Black bed ...... { 1 foot 6 inches black shale. / 2 feet 6 inches friable sandstone. }
7 feet sandstone.
9 feet 7 inches alternations of sandstone, bind, and ironstone.
10 feet shale.
2 feet seam .... { 1 foot 6 inches coal. / 6 inches bind. }
8 feet sandstone.
1 foot grey bind.
7 feet black shale.
20 feet 7 inches alternations of sandstone, bind, and ironstone.
2 feet sandstone and nodular ironstone.
30 feet sandstone.
10 feet seam .... { 5 feet coal. / 6 inches bat. / 3 feet coal. / 4 inches bat. / 2 feet coal. / 4 inches bat. }
41 feet 9 inches alternations of bind, sandstone, and ironstone.
3 inches coal.
10 feet alternations.
6 inches coal.
7 inches underclay.
3 feet bind.
51 feet sandstone.
8 feet shale.
6 feet bind.
5 feet shale.
4 feet 6 inches bind.
5 feet coal .... { 3 feet coal. / 2 feet parting. / 2 feet coal. }

17 feet bind.
6 feet strong shale.
3 feet shale.
3 feet interlaminated coal.
5 feet strong shale.

Thick coal ...... {
7 feet 6 inches coal.
1 foot parting.
3 feet 6 inches coal.
10 inches parting.
4 feet 3 inches coal.
3 inches parting.
8 inches coal.
}

20 feet bind.
3 feet coal.

After this follow about 600 feet more of these measures, of which 188 feet are obscured.

Mieke Coal-mines.

General dip S.W., 2° to 3°.

50 to 100 feet sandstone.

I. Seam ...... {
12–18 inches sandstone intermixed with coal.
6 feet coal.
12 inches shale.
}

5–6 feet shale.

II. Seam ...... {
10–12 inches soft coal.
5–6 feet coal.
2–3 inches shale.
}

20 feet sandstone.
III. Seam ...... 1–1½ foot stony coal.
50 feet sandstone.
IV. Seam ...... 3 feet bad coal.

Karatsu Coal-mines.

General dip S.W., 6°.

20 feet sandstone intermixed with bind.

2 feet seam ...... {
2 inches coal.
4 inches bind.
14 inches coal.
}

2 feet 6 inches conglomerate.

5 feet seam ...... {
1 foot coal.
10 inches bind.
22 inches coal.
7 inches bind.
14 inches coal.
}

? feet sandstone.

The comparison between these sections shows the great changes which the coal formation has been subjected to in this district.

The total production of coal in Japan has been computed by me for the year 1874 to be 390,000 tons, but for the last year (1877) will amount to at least 500,000 tons, of which about 80 per cent. are derived from the western coal-fields.

(*b*) *Copper.*—Copper-bearing veins exist in great number in Japan. The most common ore is copper-pyrites; other ores, such as variegated and grey copper-ore, black oxide of copper, and native copper, are only seldom met with*. A great number of mines are worked for copper, and amongst these the most important are situated in the northern part of Nippon (prov. Rikuchu) and in the island of Shikoku (prov. Iyo and Tosa). At the first locality the lodes usually bear from E. or N.E. to W. or S.W. Their dip is mostly vertical, and their width varies from a few inches to about 3 feet, and may be considered 1 foot on the average; copper- and iron-pyrites, galena, blende, quartz, clay, and fragments of the containing rock make up the veinstuff. At the Osarizawa mine the containing rock is usually a fine-grained rhyolite, sometimes, also, a metamorphosed clay-slate, and the lodes have a tendency to thin out in the latter. In the Ani district the copper-pyrites is often associated with considerable quantities of galena, and chiefly so in lodes approaching in their bearing to the meridian. The lodes pass here undisturbed through a decomposed rhyolite into the adjoining clay-slate.

In the neighbourhood of the Besshi mine (prov. Iyo), clay-slate, mica-schist, gneiss, serpentine, and occasionally quartzite are found interbedded, and have a bearing of N.W. to S.E. with a dip of about 50° to the N.E. The lode consisting almost entirely of a mixture of massive iron- and copper-pyrites, and quartz in small quantities, occurs interstratified with the country rock. This lode, varying in thickness from 1 to 10 feet (averaging about 5 feet), has been proved to extend for a length of about 2400 feet and to a depth of about 1400 feet below the outcrop.

A similarly composed copper-lode occurs at the Tanokuchi mine in the province of Tosa, at the junction of clay-slate and diorite. The lode is from 2 to 3 feet wide, bears E. to W., and dips to the N. at an angle varying from 40° to 70°.

Besides the above-mentioned localities, copper-ores are found also in the provinces of Uzen, Hida, Echigo, Echizen, Nagato, and Kaga, but the lodes are there much less productive. Out of a total estimated production of 3000 tons of copper per annum in Japan, the four first-mentioned mines produce about one half, and the second half is made up by nearly 200 mines distributed over the last-mentioned provinces.

(c) *Silver.*—The silver-ores most frequently found in Japan are silver-glance and antimonial silver (proustite); ruby silver (pyrargyrite), metallic silver, and an alloy of silver and gold (in about equal parts of each) are of rarer occurrence. Usually these ores are associated with other sulphuretted ores, such as copper- and iron-pyrites, galena, and blende. The most common gangue is quartz. Nearly all the silver-lodes have rhyolite as the containing rock; in exceptional cases only they are found in the older metamorphic group of rocks. The most important silver-mines are situated in the provinces of Sado, Ugo, Rikuchu, Harima, and Hida.

On the western side of the island of Sado occur three well-defined quartz-lodes, which have been mined during several centuries up to

* Red oxide of copper has not yet been found in Japan.

the present day. Two of these lodes are parallel to each other and bear from E. to W.; the average dip of the first is 65° S., and of the second 65° N. Their width varies from 3 to 25 feet, and the metalliferous portion of the veinstuff consists of silver-glance, arsenical and antimonial silver, an alloy of gold and silver, copper- and iron-pyrites, blende, and occasionally galena. One of these lodes (Torigoi) is rich in sulphuretted ores, whilst the other (Aoban) is comparatively free of them, and at the same time richer in gold and silver. Of the first lode a length of 5500 feet to a depth of 400 feet below adit-level, and of the second about 2500 feet on the bearing 700 feet below adit-level, have been mined, but the intersection of these two lodes has not been reached yet. The third lode (Hiakumai) runs from N.N.E. to S.S.W., with a dip of about 35° to the S.S.E. The width of this lode varies considerably, but only 3 feet of it in the hanging wall are mined. The veinstuff is similarly composed to that of the first-mentioned two lodes, but contains here scarcely any gold. Rhyolite, which sometimes changes into a variety resembling felsite, is the containing rock of all three lodes.

In the province of Ugo, at the Innai mine, one lode of an average width of from 4 to 5 feet, bearing E. to W., and dipping slightly to the N., occurs in a felsite belonging to the old volcanic rocks. The veinstuff consists of silver-glance, antimonial silver, copper-pyrites, and blende; the gangue is chiefly quartz, occasionally calcite. The greatest depth reached below adit-level amounts to 700 feet; but the extent to which this lode has been worked on the strike is not known.

A peculiar and interesting occurrence of silver-ore is that at the Kosaka mine (prov. Rikuchu). Irregular deposits of silver-ore are found there in a green felspathic porphyry, generally wherever this rock becomes friable or decomposed. The ore resembles an earth or sand, and consists of about 80 per cent. of silica, gypsum in small quantities, and silver probably in a state of sulphide. When richest in silver, this ore has a yellowish or reddish-grey colour. A poorer ore of a black colour (being an intimate mixture of quartz, gypsum, argentite, blende, galena, copper- and iron-pyrites) is found in pockets in close contact with the unaltered containing rock. Both these deposits appear to be confined to a certain zone about 150 feet in depth.

The quartz-lodes which are mined at Ikuno (prov. Tajima) run nearly S.E. to N.W., with a nearly vertical slightly northerly dip. They occur in rhyolite and contain silver-ores (argentite and antimonial silver) rich in gold (about 12 per cent. in the bullion produced). Their width varies considerably from less than a foot to 15 feet. The workings on these lodes are yet comparatively shallow.

At the Takaiyama mines (prov. Hida) numerous small veins containing silver-ores and galena, usually bearing N.E. to S.W., occur in a granite which, in the neighbourhood of the mines, changes into a felsite.

The total annual production of silver in Japan was estimated by me in 1874 at 2600 kwme = 315,900 oz. troy.

(*d*) *Gold.*—Most of the gold produced in Japan is derived from auriferous-silver ores; it occurs by itself in the metallic state, and in sufficient quantity to be collected by a washing process only in a few localities. The most important auriferous quartz-veins occur in the provinces of Koshiu, Ugo, and Satsuma.

At Homura (prov. Koshiu) numerous thin quartz-veins of very limited extent are found interbedded in a hard clay-slate. The metallic gold is here associated with small quantities of iron- and arsenical pyrites, blende, and galena. Owing to the hardness of the containing rock, underground mining has been carried on only on a very small scale, and the work has been confined chiefly to the washing of the alluvial deposits in the proximity of the mines. The ground in the neighbourhood of the quartz-veins is much broken up, and consequently rapidly disintegrated by atmospheric influences.

At Ooguzu (prov. Ugo) a quartz-vein about 2 feet wide, running nearly N. to S. and dipping 60° W., and numerous cross veins of smaller size, bearing N.E. to S.W., occur in a greenish soft clay-stone porphyry (probably decomposed rhyolite).

The metallic gold is here associated with copper- and iron-pyrites. A dark greyish mineral, probably sylvanite, often accompanies the metallic gold. These veins have been mined for many years past, and the gold is collected by stamping the ore and subsequent washing and amalgamation.

At Serigano and Yamagano (prov. Satsuma) numerous quartz-veins of greatly varying thickness, running E. to W. and dipping slightly N., are found in a rock resembling decomposed propylite. Usually the gold occurs therein alloyed with silver; and this alloy sometimes partially fills out cavities in the veinstuff with thin foils studded over with small cubical crystals of the same alloy.

Most of the auriferous quartz-veins in Japan are very irregular in their character and very changeable as regards their yield in gold. The total production of gold per annum in Japan was estimated by me in 1874 at 12,150 oz. troy.

(*e*) *Iron.*—About two thirds of the whole production of iron in Japan is derived from the treatment of the sand of magnetic iron-ore. The principal deposits of this iron-sand are found along the eastern and southern shores of the main island (Nippon), and usually they appear to have been derived from the decomposition of the neighbouring granitic rocks. A harder granite, less liable to disintegration, is frequently found intruded into these granitic rocks, and with the lapse of time is left behind in the shape of steep walls.

Massive magnetic iron-ore is also of frequent occurrence; the most important deposits of it are found in the northern part of Nippon in the province of Rikuchu. They occur in a mountain-ridge running N. to S., and have usually the same bearing, but are of an irregular nature and vary in thickness from 50 to 200 feet. Along the direction of the strike, outcrops have been found for a distance of about 12 English miles, and their extension in depth has on several points been proved to amount to about 1200 feet. These deposits are composed of (1) magnetic iron-ore, often possessing polarity, varying from 4·6 to 4·9 in specific gravity according to its compactness; (2) garnet, often in well-defined crystals; (3) epidote in groups of thin and tall crystals; (4) another green mineral, probably chlorite; (5) iron- and copper-pyrites, fortunately confined to certain parts of the deposits; (6) malachite and azurite, as a thin coating or exfoliation of rare occurrence.

The following analysis will show the composition of the ore at various points:—

	1.	2.	3.	4.	5 *a.*	5 *b.*
Water	0·50	0·16	0·07	0·22	1·52	0·91
Silica	6·28	7·05	7·90	18·42	13·42	12·35
Protoxide of iron	11·84	22·26	24·40	21·09	13·60	13·97
Sesquioxide of iron	69·34	54·15	57·20	52·53	59·04	62·28
Alumina	9·89	13·14	4·48	4·30	5·51	7·67
Protoxide of manganese	0·35	0·18	0·15	0·29	0·15	0·27
Lime	1·17	2·50	4·17	1·74	6·09	2·18
Magnesia	0·34	0·50	1·42	0·93	0·20	0·07
Sulphur	trace.	0·09	trace.	0·07	0·08	0·18
Phosphoric acid	0·19	0·00	0·10	trace.	trace.	0·00
	99·90	100·03	99·89	99·59	99·61	99·88
Metallic iron	57·75	55·23	59·04	53·18	51·93	54·47

No. 1. Average sample from Ohashi Maeyama.
No. 2. „ „ „ „ Shinyama.
No. 3. „ „ „ Sahinai Motoyama.
No. 4. „ „ „ Ohashi Taremizu.
No. 5 *a.* „ „ „ Sawahi Motoyama, upper.
No. 5 *b.* „ „ „ „ „ lower.

The containing rock of these magnetic iron-ore deposits changes considerably. Towards the east it usually consists of a felsite composed of orthoclase and quartz, which gradually changes into a felspathic porphyry. On the western side this rock disappears and is replaced by a diorite, often showing large crystals of hornblende. In the north-western part of the mountain-ridge chiefly granitic rocks are found; sometimes a crystalline limestone forms one of the enclosing walls of these deposits.

The formation in which these deposits occur may, in my opinion, be considered metamorphic. Future explorations yet have to prove whether the numerous deposits of the same bearing found within a distance of about 2 miles from E. to W. are parallel deposits or perhaps only spurs or branches of one main or champion mass.

Deposits of magnetic iron-ore of a similar character but of less magnitude are found in several other provinces of Japan, as Iwaki, Harima, Hoki, Hiuga, and Satsuma.

Other iron-ores, as specular iron, brown and red hæmatite, clay iron-ore, and sphærosiderite, are also found in Japan, but only in such limited quantities as to be of little interest as regards their economical value. Clay iron-ore is of the most common occurrence amongst the ores just mentioned; but owing to its more difficult treatment it has not yet been used in the manufacture of iron.

Large deposits of massive iron-pyrites are found in various localities. One of the most important is that occuring at Tashino (prov. Mimasaka). A lode from 3 to 8 feet wide, bearing from E. to W. and dipping 66° to the S., is found there in a metamorphic talcose slate, and consists of a massive iron-pyrites containing some copper-pyrites. As a rule the contents of copper increase when the lode becomes narrower. The ore raised is used for the manufacture of sulphate of iron.

(*f*) *Petroleum.*—The provinces best known as regards the occurrence of petroleum are Shinano and Echigo, of which a geological survey was begun in 1876 by B. S. Lyman; and in the following statement I shall avail myself of the published results of the first year's work*.

The petroleum is found either in yellowish-brown and grey sand-rocks, or in a dark volcanic breccia and a dark grey, slightly oily shale. The formation of the petroleum must be regarded as contemporaneous with the deposition of the volcanic breccia.

There are numerous traces of petroleum and gas in these two provinces. In Shinano there exist 22 productive wells, of which the deepest is 57 fathoms deep, and the best has a yield of 2½ barrels per day. The total yield, however, of all these 22 wells is somewhat above five barrels per day, or in a year less than 1900 barrels. In Echigo, 522 productive wells are known, of which the deepest is 122 fathoms deep, and the greatest yield of one 1·2 barrel per day. The total yields amount to 26 barrels per day, or, assuming the same production for all the year round, 9500 barrels per year.

(*g*) *Lead.*—Lead-ores are only poorly represented amongst the minerals found in Japan. They occur at Taïra (prov. Ugo), Hosokura (prov. Rikuzen), and Hakoosan (prov. Rikuchu). As regards the occurrence at Taïra, I am not in a position to furnish any details.

At Hosokura the lode occurs in a granite, and has a bearing from N.E. to S.W., and a very variable north-westerly dip. Its average thickness amounts to 4 feet, and the veinstuff is composed of galena, blende, quartz, and decomposed granite. The outcrop of this lode has been traced for a distance of more than a mile.

The lode at Hakoosan is of a similar composition, but has an average width of only 1 foot, and runs from S.E. to N.W., with a south-westerly dip in a felspathic porphyry (rhyolite). The total production of lead in Japan, per annum, was estimated by me in 1874 at 185 tons.

(*h*) *Tin.*—Tin-ore occurs only in small quantities. In the pro-

* Geological Survey of the Oil-lands. Report of Progress for the first Year. By B. S. Lyman. Tokio, 1877.

vince of Bungo, numerous eroded cavities filled with stanniferous gravel containing from 0·3 to 0·5 per cent. of tin are found in crystalline limestone.

Another locality where tin-ore has been raised is Taniyama, in Satsuma; and the ore is contained there in veins running E. to W. and traversing a porphyritic rock, probably rhyolite. These veins vary considerably in width, and are composed chiefly of quartz and iron-pyrites, in which occasionally bunches of tin-ore are met with. The estimated total production per annum is 7½ tons.

(*i*) *Sulphur.*—Two varieties of sulphur are found in Japan: the first is usually yellow or brown, derived from the condensation of volcanic fumes; and the second is of a more whitish colour and finer grain, and has been precipitated from the water of volcanic springs. Localities for the occurrence of both varieties are the numerous extinct and a few partially active volcanoes, in the neighbourhood of which hot sulphurous springs often appear at the surface. No reliable data exist as regards the annual production of sulphur and of the minerals mentioned hereafter.

(*j*) *Antimony.*—Antimony is rather scarce. In the island of Amakusa (prov. Higo), veins varying from a few inches to 2 feet occur between sandstones and schists belonging to the coal-bearing group, and the ore appears therein in thin but massive streaks.

Another more important locality is Ojoin (prov. Iyo), where an irregular deposit of antimony occurs at the junction of a volcanic breccia with the metamorphic rocks. This irregular deposit is more or less flat, and varies in thickness from 2 to 18 inches.

(*k*) *Quicksilver.*—No quicksilver is produced in Japan, but ores of the same and native quicksilver are found in two localities. In the neighbourhood of Sendai, province Rikuzen, very thin veins of cinnabar of no economic value occur occasionally in a whitish volcanic clay-rock.

A rather remarkable occurrence of quicksilver is that at Shizu, in the province of Hirado, where several layers of sandstone, about 1 foot thick, belonging to the coal-bearing group, are found impregnated with drops of metallic quicksilver, and at the same time traversed by minute veins of cinnabar.

(*l*) *Kaolin and Salt.*—With the exception of the extreme north, nearly every province of Japan has extensive deposits of kaolin, derived from the decomposition of granitic and some volcanic rocks.

Salt is found as an ingredient of several hot springs; but the amount present is so small as to render it more economical to prepare salt from the sea-water, which is most extensively practised in the southern provinces of Japan.

35. Geology *of the* Coasts *of the* Arctic Lands *visited by the late* British Expedition *under* Captain Sir George Nares, R.N., K.C.B., F.R.S. By Captain H. W. Feilden, F.G.S., and C. E. De Rance, Esq., F.G.S., Assoc. Inst. C.E. (Read April 17, 1878.)

[Plate XXIV.]

The Laurentian rocks described by Sir William Logan occupy an area of 200,000 square miles in Canada, and attain a thickness of 40,000 feet in two series, the one unconformable to the other, and, stretching northwards, form the fundamental rocks of the Polar area.

Fringing the North-American coast they plunge beneath the Silurians and Carboniferous rocks of the Parry archipelago, reappear in the gneiss cliffs of Cape Isabella, form the entire coast of Ellesmere Land, rising to heights of 2000 feet, and underlie the Miocene rocks of Port Foulke, the Miocene and Cretaceous rocks of Disco Island, Noursoak peninsula, and the Oolites of Pendulum Island, in East Greenland.

Cape-Rawson Beds.—The vast series of ancient rocks occupying the country between Scoresby Bay and Cape Cresswell, in lat. 82° 40′ N., appear to represent in time the Huronian epoch of North America; for they are evidently newer than the gneiss and crystalline rocks of the Laurentian, and older than the fossiliferous Silurians. In Nova Scotia Prof. Yule Hind has shown that the Laurentian gneiss is unconformably overlain by micaceous schists, waterworn quartz-pebbles, and gneiss-conglomerate, made up of fragments of the ancient rocks beneath, proving the very ancient period to which the metamorphism of the gneiss must be referred; and he has also shown that these gneissic conglomerates are further overlain by 9000 feet of quartzites, grits, black slates, and thin beds of auriferous quartz, which, in their turn, are probably unconformable with the gneissoid conglomerates beneath. The black slates, often gold-bearing, attain a thickness in Nova Scotia of 3000 feet; and from the analogy of their manner of occurrence, close lithological similarity, and the fact of their both preceding the incoming of the Silurian fauna, there would appear to be a strong probability that the Huronians of Nova Scotia are the equivalents in time with the rocks that constitute the north-eastern portion of Grinnell Land, which we have designated the *Cape-Rawson beds*, from the locality where they are conspicuously displayed.

The strata of Cape Rawson are thrown into a series of sharp anticlinal and synclinal folds, the axes or strike of which range about W.S.W., and abruptly terminate in the sea-cliffs of Black Cape, Cape Union, and other prominent headlands, the enormous masses of jet-black slates forming the very strongest contrast to the foreground of frozen sea and the background of snow-covered slopes—a landscape the appalling desolation of which it would be difficult to find words to paint.

The dip of these rocks is very high and often vertical, and they are traversed by true slaty cleavage, the planes of which are sometimes horizontal, much more often inclined at high angles, their strike being N.N.E. Associated with these slates are impure limestones frequently traversed by veins of quartz and chert. Further to the north, commencing in latitude 82° 33′, the above-mentioned rocks give place to a vast series of quartzites and grits, rising to elevations of 2000 and 3000 feet on either side of Westward-Ho valley, through which passes an anticlinal axis which carries the rocks down below the Carboniferous Limestone of Feilden peninsula.

Dr. Conybeare was perhaps the first to recognize (in 1832) the presence of Upper Silurian fossils in collections brought from the Arctic archipelago; and the subsequent study of the late Mr. Salter and Dr. Haughton supported this identification, and referred the horizon to that of the Niagara and Onondaga groups, the equivalents of our Wenlock and Dudley. These limestones occupy the south of North Devon and nearly all the islands south of Melville and Lancaster Sounds, including the south of Banks's Land, Prince Albert's Land, Prince of Wales's Land, King William's Land, North Somerset, Boothia Felix, &c.

Upper Silurian fossils occurring in a conglomerate resting on the Laurentian rocks of the Hudson-Bay Territory, observed by Sir John Richardson, caused Sir Roderick Murchison and others to believe that the entire Polar area was dry land during the whole time occupied by the deposition of the Lower Silurian rocks elsewhere.

But the specimens brought by the late Expedition, and identified by Mr. Etheridge, prove that this is not the case, and that the Lower and Upper Silurians are both present on the shores of Kennedy Channel.

From the occurrence of Lower Silurian forms among the species collected by M'Clintock in cream-coloured dolomite around the magnetic pole, on the western coast of Boothia, in King William's Island, and Prince of Wales's Land, there would appear to be little doubt that these dolomites represent the whole of the Silurian, and possibly a part of the Devonian.

The base of the Silurians consists of finely stratified Red Sandstone and slate in North Somerset, where it is overlain by ferruginous limestones with quartz-grains, underlying pale cream-coloured limestone dipping 5° to N.N.W.

The coarse basement beds are seen on Cape Warrender and Wolstenholm Sound, and to this horizon the basement beds of the Silurians of the south coast of Bache Island may be referred; these rest on syenitic and granitoid rocks, and are overlain by mural cliffs of limestone, rising to a height of more than 1000 feet, dipping gently to N.N.W. as far as Victoria Head, where a landing was effected and a small collection of fossils obtained.

The northern shore of Bache Island presents a very straight line of mural cliff composed of this formation, coinciding in direction with its strike.

Norman-Lockyer Island (lat. 79° 25′ N.) lies at the mouth of

Franklin-Pierce Bay, and is separated from the mainland by a fault. It is composed of a grey argillaceous limestone, splitting easily from the action of the weather. The dip is to the north at a high angle, as the island on its southern faces rises as a steep bluff from the sea, some 600 feet, shelving to the water on its northern side. The summit is marked with glacial scratchings running in a north and south direction. Veins of calcite or carbonate of lime traverse the rock of this island in several places. Fossil organisms are not numerous, but those obtained exhibited a decidedly Silurian facies*. The basement conglomerate is not seen on Norman-Lockyer Island, but is brought up by an east and west fault to the north of it, and reappears at Cape Prescott, where it is overlain by limestones similar to that of Victoria Head. Both conglomerate and limestones continued exposed in the cliffs of Allman and Dobbin Bays, Cape Louis Napoleon, and Hayes Point. An anticlinal axis ranges north-east through Cape Hilyard, along which more ancient Silurians appear to be exposed, as Mr. Etheridge has determined some of the fossils from this locality, and others in the neighbourhood, to belong to Lower Silurian types, as *Maclurea magna*, *Receptaculites occidentalis*, *R. arctica*. The Silurian limestones continue to Cape Norton Shaw; and at Cape Barrow, as well as in the localities previously described, a very numerous assemblage of fossils has been obtained, including the genera *Orthoceras*, *Strophomena*, *Rhynchonella*, *Macrocheilus*, *Favosites*, and *Halysites*. These rocks are not found on the northern side of Scoresby Bay, where they give place to a more ancient formation of probably Huronian age; the line of junction is not seen, and it is doubtful whether the two formations are faulted against each other, or whether the Silurians are deposited on the older strata.

The boundary, of whatever character it may be, traverses Kennedy Channel, and reappears in Hall Land, traversing the country from Polaris Bay to the southern end of Newman Bay, its situation being determined within narrow limits by the occurrence of Cape-Rawson beds at Thank-God Harbour to the north, and of Silurian limestones at Cape Tyson and Offley Island to the south, whence the limestones extend to both sides of Petermann Fiord and Bessel's Bay, and southward by way of Franklin and Crozier Islands, Capes Constitution and Andrew Jackson to the great Humboldt glacier, and they doubtless underlie the whole of the ice-cap covering Washington Land.

Above these Silurians lie the coal-bearing sandstones of Melville Island and Banks Land, occupying a synclinal and overlain by the Mountain Limestone.

From the identity of many of the species of plants found in the shales associated with the coals with those of the rocks lying at the base of the Spitzbergen and Bear-Island Mountain Limestone, Prof. Heer has referred this group to his "Ursa stage," which he considers to be of Lower Carboniferous age.

* Amongst them may be noted *Favistella reticulata*.

The identity of genera and of some species in these beds, which contain the first rich land-flora the earth ever saw, with those of the European Carboniferous beds, points to an equable condition of climate prevailing over a very large area of the earth's surface.

Dana-Bay Beds.—A few Devonian forms have been recorded from the Parry archipelago, but this formation has never satisfactorily been determined there. In South-west Greenland certain unfossiliferous red sandstones have been doubtfully referred to this formation, as have the Russian-Island limestone and shales of Spitzbergen and Bear Island, underlying the "Ursa stage" of Prof. Heer; but these limestones contain no determinable fossils, and the Devonian fauna had never yet been found within the Polar area until the discovery of what we have termed the Dana-Bay beds, which contain fossils identified by Mr. Etheridge as Devonian forms.

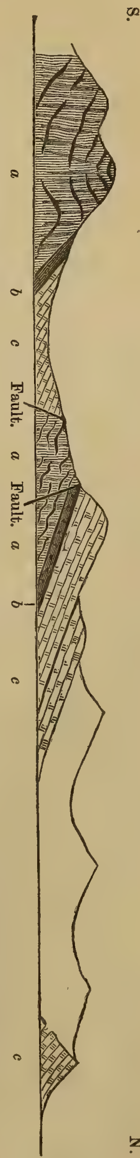
The exposure of the Devonian rocks was observed in a small torrent-course, and could not be traced over any considerable area, so that their relation to the underlying rocks unfortunately could not be determined; it is therefore still an open question whether or not these beds represent in part the *Ursa stage* of Prof. Heer, and whether they constitute the base of the Grinnell-Land Carboniferous Limestone as it does that of the Parry archipelago.

In the Dana-Bay Devonian occurs a species of *Spirifera*, and *Productus mesolobus* or *costatus*.

If the rocks of the Ursa stage be absent in Grinnell Land, it would appear probable that they were deposited in isolated basins, occupying the archipelago area, and not extending so far north as Grinnell Land.

Green slates and metamorphic rocks belonging to the Cape-Rawson beds are seen on the hill-side below the Carboniferous Limestone in the neck of Feilden Peninsula. Whether the boundary is a natural or a faulted one is doubtful; but the latter is the most probable, from the fact that the Dana-Bay beds on the south side of the valley underlie the Carboniferous Limestone, which is here repeated by a strike-fault, while on the north side these beds are not seen and the basement beds of the limestone appear to be cut off by a fault.

Section through Feilden Peninsula to Cape Joseph Henry.



a. Cape-Rawson Beds. b. Dana-Bay Beds. c. Carboniferous Limestone.

Carboniferous Limestone.—An exposure of rocks of this age occurs on the north coast of Grinnell Land, in Feilden and Parry Peninsulas, and as far west as Clements-Markham Inlet, rising, on Mount Julia, to a height of over 2000 feet, and probably attaining a still higher elevation in the United-States range, which coincides in direction with that of the limestone of the coast. There would also appear to be a strong likelihood that the limestone continues in a south-westerly direction by way of these mountains across the whole of Grinnell Land, and is connected with the limestones forming the well-known synclinal of that formation occupying so large a portion of the Parry Archipelago.

A large number of fossils from this region have been identified by Mr. Etheridge; amongst them may be mentioned *Productus costatus, Spirifera ovalis*, and *S. duplicicosta*. It is noteworthy that the explorers did not meet with this formation on the northern shores of Greenland; and it is observable that a continuation of the direction of the known strike of the limestones of Feilden Peninsula, carried over the Polar area, passes through the neighbourhood of Spitzbergen, where this formation occurs, and contains certain species identical with those of the Grinnell-Land rocks of this horizon.

No Secondary rocks were discovered in the more northern lands visited by the Expedition, though they occur in several other portions of the Arctic area.

Jurassics.—Liassic fossils were long ago discovered by Lieut. Anjou, of the Russian Navy, in New Siberia; and at Point Wilkie and other localities in the Parry Archipelago patches of Lias with a numerous fauna occur, resting on the denuded edges of the Carboniferous Limestone, and rising to a height of 567 feet above the sea on Exmouth Island, where Sir Edward Belcher discovered the saurians described by Prof. Owen.

Saurians also occur in Spitzbergen (*Ichthyosaurus polaris* and *I. Nordenskiöldii* of Mr. Hulke) in beds of black bituminous shales, interstratified with hyperite, limestone, and sandstone, referable to the Trias and Lias.

The saurian vertebræ named by Dr. Leith Adams *Arctosaurus Osborni* were found in the Lias beds of Bathurst Island by Admiral Sherard Osborn.

Jurassic rocks with *Myacites? liassinus, Belemnites paxillosus*, and an Ammonite near to *biplex* occur at Katmai Bay, on the south coast of the promontory of Alaska, examined by M. Wosnessenskii.

On the east coast of Greenland Lieut. Julius Payer and Dr. Copeland discovered marls and sandstones, on the east coast of Kuhn Island, with a fauna resembling that of the Russian Jurassics, characterized by the presence of the genus *Aucella*, which is found from the Lower Volga northward to the mouth of the Petschora, and occurs in Spitzbergen (*A. mosquensis*), its western limit being the east coast of Kuhn Island, in which *A. concentrica*, Keys., in five varieties, connected by intermediate forms, occurs, associated with an Ammonite (*Perisphinctes Payeri*, Toula) somewhat allied to *A. involutus*, Quenst., *A. striolaris*, Rein., *Belemnites Panderianus*, D'Orb., *B. volgensis*, D'Orb.?, *B. absolutus*, Fisch., and a *Cyprina* near to *C. syssollæ*, Keyserl.

On the south coast of the island are coarse-grained, brownish micaceous, and light-coloured calcareous sandstones and marls, believed to be of the age of the coal-bearing Jurassics of Brora, Skye, and Mull (Scotland), and the Middle Dogger of Yorkshire. Amongst the fossils are:—*Goniomya v-scripta*, Sow.; *Avicula Münsteri*, Goldf.?, a Bradford-clay form; *Belemnites fusiformis*, Quenst.?, and *Nerita hemisphærica*, Röm.?, Great-Oolite forms; and *Rhynchonella fissicostata*, Suess.

The Cretaceous rocks of North-western America, which in the Missouri valley spread over an area of no less than 80,000 square miles, have been shown by Messrs. Hayden and Meek to consist of five subdivisions, the lowest being the Dakota group, which contains dicotyledonous leaves and seams of lignite, and underlies the Fort-Benton and Niobrara groups, containing marine fossils of the age of the English Grey or Lower Chalk.

Within the Arctic area beds of Cretaceous age have only been observed on the northern coast of Disco Island and the southern side of the Noursoak peninsula, the beds of the former locality being the most ancient, and named by Prof. Nordenskjöld the "Kome Strata;" they reach 1000 feet in thickness, occupying undulating hollows in the underlying gneiss, and dip towards the Noursoak peninsula at 20°, where the overlying "Atane Strata" come in.

Both these series contain numerous plant-remains and seams of lignite*, which have been collected by the Greenlanders for their personal use; and in neither occur the marine beds of the United States.

The presence of the leaves of dicotyledonous plants, as *Magnolia alternans*, Heer, in the Atane strata links them with the Dakota of the United States, with which they have several species in common.

The underlying Kome beds do not appear to be present in the American area; they are characterized by the beautiful Cycads (*Zamites arcticus*, *Glossozamites Hoheneggeri*) stated by Prof. Heer to occur in the Urgonian strata of Wernsdorff. (See Table, p. 562.)

* Three analyses of Disco-Island coal are recorded, but whether of Cretaceous or Miocene age is doubtful, except the last, which is Miocene.

No. 1 by Prof. Fyfe, of Aberdeen.

No. 2 by Mr. Keates, of London.

No. 3 by Prof. H. Wurtz, of a specimen brought by the U.-S. ship 'Juniata' in 1873, in 'American Chemist,' vol. iv. p. 401, and in Proc. of New York Lyceum of Nat. Hist. 2nd ser. no. 4, p. 119.

	I.	II.	III.
Gaseous or volatile matter	45·45	50·60	35·38
Moisture	·75	—	14·00
Sulphur	·55	—	trace
Coke { Fixed carbon	47·75	39·86	41·79
Coke { Ash	5·50	9·54	8·83
	100·00	100·00	100·00
Specific gravity	1·369	1·384	

Table of Cretaceous Rocks.

Grinnell Land.	Greenland.	N.W. America.		Europe.
Absent	Absent	FOX-HILL BEDS Formation no. 5 *Ammonites lobatus*	500 feet	*Sénonien*, D'Orbigny. Upper or White Chalk and Maestricht beds.
		FORT-PIERRE GROUP Formation no. 4 *Ammonites complexus* *Mosasaurus missouriensis*	700 ,,	
Absent	Absent	NIOBRARA GROUP Formation no. 3 *Inoceramus problematicus* Four birds, thirty-seven reptiles, and forty-eight fishes, of genera nearly all of which occur in the chalk of Europe.	200 ,,	Lower or Grey Chalk and Upper Greensand.
		FORT-BENTON GROUP Formation no. 2 *Ammonites Mullani*	800 ,,	
Absent	ATANE STRATA	DAKOTA GROUP Formation no. 1 Dicotyledonous leaves, silicified wood, and seams of lignite.	400 ,,	
	KOME STRATA.	Absent.		Gault and Neocomian.

The five divisions of the American Cretaceous were first established by Messrs. Hayden and Meek in 1860, in Proc. Acad. Nat. Sciences of Philadelphia, for the Missouri valley, an area of 80,000 square miles. See also 1st, 2nd, and 3rd Annual Reports, U.S. Geological Survey of the Territories, 1873, p. 49.

The great series of Tertiary deposits that occupy so extensive an area have been shown by the labours of Mr. Lesquereux and others to exhibit a succession of floras, the lowest characterizing tropical conditions, fan-palms and bones of *Crocodilus* abounding, which gradually disappear in the higher beds, of probably Miocene age, until in the Middle and Upper Miocene palms have entirely disappeared.

To these latter horizons may be referred the Miocene rocks within the Polar area occurring at Disco Island, where they reach a considerable thickness, and are associated with the sheets of basalt which have been so frequently described since they were first noticed by Sir Charles Giesecke in 1821. These appear to separate the lower plant-bearing beds (2000 to 3000 feet) from the upper or lignitic series, which, however, contains the same flora which reappears in the plants collected by the late Expedition from the Miocene rocks of Lady-Franklin Bay, recently described before the Society by Prof. Heer, in Jan Mayen Island, and in the black shales of Cape Staratschin, in Spitzbergen, and in the brown coals of Franz-Joseph Land.

The Spitzbergen beds are remarkable for a marine bed being intercalated in the estuarine series, generally characteristic of the Arctic area. Amongst the fossils occur *Terebratula grandis*, *Dentalium incrassatum*, *Corbula Henkelinsi*, and *Natica phasianella*.

The marine beds appear to be exceptional, and the greater mass of the 1500 feet of strata of Miocene age are of freshwater origin, and contain brown coal, plant-remains, and twenty-six insects.

Of the thirty species of plants obtained from the Grinnell-Land Tertiary beds*, discovered by the Expedition, eighteen occur in the Spitzbergen flora, with which, Prof. Heer points out, it closely approximates, and marks somewhat colder conditions than are expressed by the character of the plants in the Disco-Island Miocenes, 11° further south.

Six species of the Grinnell-Land flora are common to Europe, one of them being the fir (*Pinus abies*), which in Miocene times was confined to the Arctic zone, and now in Scandinavia never ranges north of 69½° N. (See Table of Tertiary Deposits, p. 564.)

Glacial and later deposits.—There is no point of Arctic geology of greater interest than the occurrence of water-margins at successive elevations in Smith Sound, rising to heights of from 200 to 300 feet, in situations where wave-action was impossible. These ancient sea-margins are most persistent in bays, inlets, and narrow arms of the sea, and are still in process of formation.

Subaerial denudations of the surfaces of the cliffs cause vast masses of material to fall during the thaw of the short summer, on a scale so gigantic that the mind fails to realize it, unless it has been actually witnessed.

The base of the cliff is concealed by a talus made up of a shifting mass of material resembling those known as "screes" in the English lake-district, and like them chiefly supplied by fragments from the deep gullies or "rakes" which seam and scar the cliffs above, and act as channels for the passage of the frost-worn material of the

* Already described in the Quart. Journ. Geol. Soc. vol. xxxiv. p. 66, by Prof. Heer. The coal associated with these beds has recently been analyzed by Mr. R. J. Moss, F.C.S., and found to contain:—

Carbon	75·49
Hydrogen	5·60
Oxygen and nitrogen	9·89
Sulphur	0·52
Ash	6·49
Water	2·01
	100·00

—*Scientific Proc. Royal Dublin Soc.*, 1877.

uplands. The destruction of rock is not merely confined to these particular lines of erosion, but is continuous over the whole surface of the country during the episodes of summer thaw. In those climates the approach of winter is not marked by any transition. Beyond the limits of perpetual snow the land at the close of the transient summer is saturated with moisture; the fissured precipice, the cleaved slate, and the gravel-bed are alike charged with water to their utmost capacity; without any warning, winter lays her icy hand on the scene, and in a few hours the face of nature is changed, and moisture and running water is converted into ice.

Table of Tertiary Deposits.

Arctic area.		N. America; West North America; Canada.	
Absent..........	Pliocene	LOUP FORK of Platt River.......... *Canis Felis, Equus, Mastodon, Helix.*	300–400 feet.
Spitzbergen...... Grinnell Land.. Disco Island ...	Upper Miocene.	WHITE-RIVER GROUP. Freshwater clays.......... *Oreodon, Rhinoceros, Machairodus, &c.* Green-River group.	1000 ,,
	Middle Miocene.	WIND-RIVER GROUP. Freshwater sandstones.......... *Trionyx, Testudo, Helix,* wood. Carbon coal and Bitter-Creek series in part. Palms have disappeared.	1500 ,,
	Lower Miocene.	WAHSATCH GROUP .... Green-River group in part . Evanston group .... } American Upper Eocene (*Lesquereux*).	
Absent..........	Eocene..........	Upper Missouri region. Colorado and New Mexico coal-basin. FORT-UNION BEDS, a lignitic group .... Fan-palms, *Populus, Crocodilus, &c.*	2000 ,,

The destructive force exercised upon rocks during the progress of expansion throughout the entire Polar region is a most potent factor, and gives results but little comparable with the subaërial work now going on in temperate climes. On the first signs of thaw large masses of rock, separating along lines of weakness formed by planes of jointing and bedding, are detached from the cliff, and falling on the "screes," slide down to the ice-foot beneath, the impetus being often sufficient to carry them on to the floe, where they remain until the general break up of the ice, when vast quantities of material are drifted seaward.

The ice-foot appears to be formed not so much by the act of freezing of the sea-water in contact with the coast, as by the accumulation of the autumn snow-fall, which, as it drifts to the beach, is met by the sea-water at a temperature just below the point of freezing of fresh water, and instantaneously converted into ice, forming a solid wall from the bottom of the sea. This wall is constantly increasing in height from snow-falls. When the young ice or "season floe" is formed at the surface of the sea adjacent to the ice-foot, there is little difference between the level of the floe and the ice-foot; but as the latter is constantly increasing in height, and the former is twice daily oscillating with the change of tides, it is easy to see how a line of junction is impossible; and the height of the surface of the ice-foot above the level of high water is mainly dependent on the amount of snow-fall, while its depth below that level is dependent upon the slope of the sea-bottom and the vertical range of the tides. It is almost needless to observe that on exposed and projecting headlands the ice-foot, like the beaches of temperate regions, is invariably absent.

It is not, however, until near the close of the thaw episode that the ice-foot is discovered to be the cause of the production of the remarkable terraces to which we have alluded.

The typical aspect of the ice-foot in Smith Sound is that of a terrace of fifty to a hundred yards in width, stretching from the base of the "scree" to the water's edge, its width varying with the slope of the sea-bottom, decreasing in direct proportion to the increase of the land slope.

The first action of the solar rays is exerted on the snow forming the uppermost layer of the ice-foot which lies nearest to and upon the talus or "screes," the dark surfaces of which rapidly absorb the heat of the sun. A deep trench is formed at the junction, which becomes filled with water, partly derived from the melted snow of the ice-foot and partly from that pouring down from the uplands; these united streams in a few hours eat deep channels across the ice-foot and discharge themselves into the sea through transverse gullies, often exposing the underlying talus, and more rarely the subjacent rock. At low water the ditches and gullies are drained, whilst at high water the sea pours in through these apertures with considerable violence, and sweeping right and left, traverses the ditch, eats away the base of the talus, and reassorts the material.

As the progressive elevation of the coast of Grinnell Land continues, degradation of the older terraces ensues, and the materials of which they are composed are shifted to lower levels, and go to make up the terraces now in process of formation.

Where degradation has been excessive all traces of older terraces are obliterated; but numerous fragments of these terraces preserved by a protective snow mantle remain to attest their former continuity.

Sea-ice driven on shore by gales, or moving up and down with the tides, is a very potent factor in glaciating rocks and pebbles. Along the shores of the Polar Basin this process of glaciation was seen in progress by one of us; and he records in his 'Journal' that at the south end of a small island in Blackcliff Bay (lat. 82° 30′ N.) the bottoms of the hummocks, some eight to fifteen feet thick, were studded with hard limestone pebbles, which were rounded and scratched as distinctly as others taken from moraines; when extracted from the ice, only the exposed surfaces, as a rule, were glaciated. As the tide recedes the hummocks do not always arrive at a position of rest without some disturbance of the subjacent material, particularly on a shelving shore, and the sliding of the hummock to a lower level and the sound following on the grating together of the pebbles beneath may be noted. In many places where gaps occurred in the lines of ancient sea-terraces, the basement rock, as well as some of the pebbles in the terraces, were found to be glaciated, and there can be no doubt that this is due to the action of shore-ice, the condition of the terraces precluding the idea that it might have been the result of glacier action.

Pushed-up mounds or long ridges of gravels, both at the sea-level and at various elevations, are a conspicuous feature along the shores of the Polar Basin; these sometimes extend at the edges of deltas in long lines of mounds like giant mole-hills.

A careful examination of the fossil remains found in the recent beds of Grinnell Land and North Greenland, extending from an altitude of 1000 feet to the present sea-level, give unmistakable evidence that the fauna is practically identical with that now existing in Grinnell Land as well as in the neighbouring sea. The remains of Mammalia, such as the lemming (*Myodes torquatus*), the ringed seal (*Phoca hispida*), the reindeer (*Cervus tarandus*), and musk-ox (*Ovibos moschatus*), were discovered in these beds. The marine Mollusca most abundant as living species in the adjacent seas, such as *Pecten grœnlandicus*, *Astarte borealis*, *Mya truncata*, and *Saxicava rugosa*, are also the most abundant species throughout the mud-beds, whilst the stems of two species of *Laminaria*, which appear to grow in considerable abundance in the Polar Sea, were detected in mud-beds, at an elevation of 200 feet, still retaining their peculiar sea-shore odour. Coniferous drift-wood, of precisely the same character as that now stranded, was found at elevations of several hundred feet, and so little altered by time or climate that it still retained its buoyancy. The species of the Post-tertiary and Recent Mollusca have all been determined by Dr. Gwyn Jeffreys, who has described the collections made by the Expedition at twelve stations*, and identified those from Stations 13 to 27, described by one of us†.

* "The Post-tertiary Fossils procured in the late Arctic Expedition; with Notes on some of the Recent or Living Mollusca from the same Expedition," Ann. & Mag. Nat. Hist. 1877, vol. xx. p. 229–242.

† "Post-tertiary Beds of Grinnell Land and North Greenland," by H. W. Feilden, F.G.S., C.M.Z.S., with Note by J. Gwyn Jeffreys, LL.D., F.R.S., Ann. & Mag. Nat. Hist. 1877, vol. xx. pp. 483–494.

DANGERFIELD, LITH. LONDON.

× × Glacial Drift, Shell stations.
Miocene, Plant & Coal beds.
Carboniferous Limestone.
Silurian Limestones and Conglomerate.
Cape Rawson Beds. (Huronian ?)
Mica Schists & altered rocks.
Cape Isabella Gneiss. (Laurentian ?)

The accounts given of trees having been found in similar Post-pliocene beds in the Polar regions, under circumstances that would lead to the supposition that such trees had grown *in situ*, are not to be relied on; and no evidences were discovered in the mud-beds of Grinnell Land to encourage the opinion that there have been any interglacial periods of increased temperature, at all events during the long time which must have elapsed while Grinnell Land was rising to an altitude of 1000 feet above the present sea-level.

Dr. R. W. Coppinger, who accompanied Lieut. Fulford in his exploration of Petermann Fiord in May and June 1876, after leaving Offley Island some fifteen miles, found the fiord to be bounded by vertical cliffs 1100 feet high, composed of alternating bands of light grey and dark slate-coloured fossiliferous limestone rock, surmounted by an ice-cap, with a blue jagged edge lying flush with the face of cliffs, which was estimated to be 40 feet in thickness. A similar ice-cap prevailed on the south-west side; and on both sides the ice appeared to be flowing steadily over the cliffs, as evidenced "by frequent avalanches, in which great masses of the ice-cap projecting over the cliffs become detached, and carrying with them in their descent masses of rock torn from the face of the cliffs," sometimes projected on to the floe a distance of 80 yards.

The surface of the ice of the floe is traversed by north and south ridges running obliquely down the fiord for a distance of sometimes two miles, though usually interrupted by wide fissures and faults, which become more numerous as the glaciers are approached. These form nuclei of disruption of the main ice. At certain states of the tide the glacier-ice appeared to be aground, and at others to behave as floe-ice. The depth of the furrows on the floe, measured from crest to trough, was often 30 feet, and the sides exceedingly slippery and difficult to travel on, and the glacier-ice was equally formidable; but enough was seen to render it certain that the fiord had been occupied by an immense glacier, which has retreated to its present dimensions, and whose main course lay to the east, the small glaciers flowing through the cliffs adding little to the volume of ice, which is affected by tidal action for more than a mile above the mouth.

The whole of Offley Island is traversed by glacial planings, scorings, and groovings, from its summit at the north-east, down to the beach at the south-west end, the rock consisting of fossiliferous black and grey limestone.

A very noticeable feature of Grinnell Land is the paucity of glaciers and the non-existence of an ice-cap, such as prevails in North Greenland. In Grinnell Land, north of latitude 81°, no glaciers descend to the sea-level, which they do in the same parallel on the opposite or Greenland coast of Hall Basin*.

EXPLANATION OF PLATE XXIV.

Sketch Map showing the Geology of Grinnell Land and the neighbouring regions.

* For the Discussion on this paper, see p. 636

36. PALÆONTOLOGY *of the* COASTS *of the* ARCTIC LANDS *visited by the late* BRITISH EXPEDITION *under* Captain Sir GEORGE NARES, R.N., K.C.B., F.R.S. By R. ETHERIDGE, Esq., F.R.S., V.P.G.S., &c. (Read April 17, 1878.)

[PLATES XXV.–XXIX.]

INTRODUCTION.

IT is no easy matter to parallel or attempt to correlate the older Palæozoic rocks of the northern extremity of British North America with the probably contemporaneous rocks extending as far northward as within 7° of the Pole, much more with those of Northern Europe and Britain.

The collection made by Capt. Feilden, Lieut. Aldrich, Drs. Coppinger and Moss, and Mr. Hart clearly shows that great masses of metamorphic and Palæozoic rocks occur, and occupy an extensive area, both in Grinnell Land, Grant Land, and Greenland, Whether these can be shown to be a continuous portion of the Laurentian * or Huronian rocks of Canada, or the fundamental or oldest gneiss of the north-west coast of Scotland and the Western Islands, remains yet to be proved. There is every probability that these ancient hornblendic schists do extend from North Britain to North America, and underlie the greater part, if not the whole, of the North Atlantic and Polar Sea.

Hitherto the Laurentian type of Canada has not been discovered in the British Isles, neither have we amongst the 'Alert' and 'Discovery' collections any specimens that can be said to agree with the Magnesian and Eozoonal conditions of this fundamental rock. The North-Atlantic Ocean, which occupies so large an area, may, indeed, rest upon a great expansion of our Hebridean Gneissose series, and Huronian or Cambrian and Silurian rocks may overlie this; and probably, if clear sections could be seen, and superposition determined, they would be found to pass upwards into the Potsdam or Lower Silurian series of America. The extensive collection of rock-specimens made indicates this probable succession; and few as are the Lower-Silurian fossils brought home, they are enough to show the succession to be much the same as in British North America and the British islands; and the Upper Silurian fossils of Dobbin Bay, Cape Hilgard, Cape Louis Napoleon, Offley Island, &c. confirm this unmistakably. Moreover we are enabled to correlate these Upper Silurian fossils with the Wenlock group of Britain; but, nevertheless, they have a facies allying them to the American types rather than to our own.

* Laurentian rocks are noticed at pp. 324, 327, and 541 of the 'Arctic Manual.'

Succeeding these, in lat. 82° 40′, there appears to be a Devonian series, judging from the broad-winged *Spiriferæ* brought home from Cape Joseph Henry and Feilden Peninsula, lat. 82° 47′; and probably much of the extreme northern coast of Grinnell Land contains a clearly developed Carboniferous-Limestone fauna identical with that so widely distributed over the North-American continent, and referable also to our British and Spitzbergen species. Of the Coal-measures above them (if they occur) we know nothing at present.

The large series of fossils obtained during the voyage of H.M. ships 'Alert' and 'Discovery' was placed in my hands for examination. The chief interest attached to the series arises from the fact that no previous expedition had reached so high a latitude, and certainly no collection ever exceeded in magnitude that under examination, which, including the rocks, comprises nearly 2000 specimens. Great credit is due to those who collected and succeeded in bringing or conveying them through the arduous sledge-journeys to their respective ships. The series collected by Captain Feilden are all so carefully noted, labelled, and localized, that their history is complete and satisfactory; so also with the fine series belonging to Dr. Coppinger: rarely, indeed, in the most accessible localities in Britain, have specimens been better or more carefully collected than by the officers of the Expedition. The fossils of Miocene age, collected by Messrs. Feilden and Moss from Discovery Bay, were sent to Prof. O. Heer, of Zurich, for determination; and that distinguished naturalist has furnished a valuable report upon the fragmentary remains of the fossil plants (chiefly leaves) occurring in the black shales that overlie the great coal-seam at Discovery Bay, which is undoubtedly of Miocene age and the same as that at Disco Island. Prof. Heer catalogues no less than thirty species, and has been enabled to correlate these with the Spitzbergen Miocene beds: about eighteen species are common to the Miocene flora of the Arctic zone; and, so far as the collection shows, the Discovery-Bay (Grinnell Land) Miocene beds are more nearly allied to the Spitzbergen deposits than to the Disco or Southern-Greenland beds, 11° further south. Species of *Equisetum*, *Torellia*, *Thuites*, *Taxodium*, *Pinus*, *Populus*, *Salix*, *Betula*, *Corylus*, *Ulmus*, *Viburnum*, *Nymphæa*, &c. occur in the black shales overlying the great coal-seam. None of the above genera now exist within the Arctic circle. A small collection of Silurian Mollusca and Corals from Cape Joseph Henry has also been sent to me by Dr. Moss, of the ship 'Alert.' A considerable number of the rock-specimens and minerals have been named by Mr. W. Rudler, and the remainder by myself; at present no deductions have been drawn from the result of this examination. Large numbers of specimens of fundamental gneiss, mica-schist, quartzites, slates, impure limestones, and conglomerates occur in the collection, affording complete evidence as to the geology and physical structure of the coasts on both sides of Smith Sound, Kennedy Channel, Hall Basin, and Robeson Channel, and round the north shore of Grinnell Land, the most northerly land ever yet reached. The series of rocks collected by Lieut. Aldrich, R.N., during the arduous journey made by his party with the "'Alert' and 'Discovery's' dog-sledges," may never again be obtained; they now illustrate the structure of the nearest known land to the Pole, in latitude 83°, and were brought back to the 'Alert' under the greatest difficulties and privations.

Much has been done relative to Arctic geology and palæontology by previous writers, with regard to the North-American continent, Spitzbergen, and Scandinavia, as well as in those latitudes bordering the Polar circle; still every new expedition or voyage increases our knowledge of the fossil fauna and flora of these regions, notably so the present, under the command of Captain Sir G. Nares, whose officers penetrated as far north as lat. 83° 6′, head or winter quarters being in lat. 82° 27′. During the memorable sledge-journeys from the 'Alert' and 'Discovery,' the most northerly land yet known was searched, and the practical result conveyed back to the ships in the shape of a large collection of rocks and fossils made along the northern shores of Grinnell Land, from Cape Joseph Henry, lat. 82° 47′ N., long. 63° 50′ E., to Cape Alfred Ernest, lat. 82° 15′ and W. long. 80°, Feilden Peninsula, lat. 82° 50′, Point Hercules, lat. 82° 40′, and Cape Columbia, 83° 6′, the most northerly headland known; collections were also made at Port Foulke, Cape Isabella, Discovery Bay, Lincoln Bay, Cape Union, Offley Island, and Petermann Fiord; also at Hayes Sound, lat. 78° 50′, Cape Frazer, lat. 79° 44′, Cape Victoria, lat. 79° 12′, Walrus Island, lat. 79° 25′. At all these stations collections were made from rocks *in situ*, a matter of much importance to a right interpretation of the sequence or stratigraphical position of the specimens. It appears that a great thickness of unconformable and unfossiliferous Archæan (azoic) rocks, of younger date than the Laurentian or fundamental gneiss, but older than the Silurian series, occupy the east shores of Grinnell Land from Scoresby Bay to Cape Cresswell, lat. 82° 40′, and east of Robeson Channel, on the Greenland coast, equivalents in time of the great Huronian series of North America and Canada; whether continuous or not it is perhaps impossible to say at present. These "Archæan" rocks, which constitute the great Azoic series (Laurentian and Huronian), and preceded the Cambrian and Silurian, seem to occupy the position mentioned; for the present the name "Cape-Rawson beds" has been applied to them as applicable to the geographical position and distribution of these extremely northern azoic rocks, thus avoiding a strict and uncertain correlation with the known American "Archæan" rocks. No organic remains whatever have occurred in these Cape-Rawson slates, quartzites, grits, and impure limestones, which constitute masses of land 3000 feet high. The physical structure and aspect of these ancient schists have been described by Captain Feilden and Mr. De Rance, F.G.S.

Looking at the facies of the fossils in the collection, and comparing them with the fauna of North America and Canada on the one side, and that of Greenland, Spitzbergen, Scandinavia, Europe, and Britain on the other, it becomes a difficult question to which area and faunal type we may or can safely refer them; in other words, Are the species in the Arctic collection more closely allied or equivalent to those of Arctic America, or to the fauna of the western hemisphere? or can they be equally referred to that of the northern part of the European continent, especially Norway and Sweden or the Scandinavian peninsula, or to the British islands? Many species are common to both areas, especially in the groups of the Cœlenterata and Brachiopoda, the latter markedly in the Carboniferous series.

It cannot be doubted that an extensive Silurian fauna is present from lat. 79° to lat. 82° N., illustrating the lower and upper divisions, the latter largely, especially the Wenlock series. A few Devonian *Spiriferæ* occur in the collection, succeeded by a characteristic series of Carboniferous-Limestone Mollusca (Cephalopoda, Gasteropoda, Brachiopoda, and Polyzoa)—all other Palæozoic rocks, so far as we know, being absent, no Coal-measure or Permian species occurring in the collection.

Our knowledge of the distribution of life through the rocks of the Arctic region and within the Polar circle, as well as our information relative to the general geology, mineralogy, and petrology of the Polar regions, has been largely added to by the collections made during the present expedition. A more general series of fossil Invertebrata has been collected, and a fine series of the rocks composing the Laurentian, most of which have been obtained *in situ*, others from the drift, or borne upon glaciers from higher regions, probably remote from the coast, or from the talus which abounds under the cliffs constituting so conspicuous a feature along the shores of Grinnell Land, Petermann Fiord, and Hall Land—in fact, on both sides of Robeson and Kennedy Channels. A large number of slabs and masses of limestone were also obtained from the last-mentioned sources; these contain organic remains, which plainly tell their age, but not their locality, though I believe that nearly all, if not all, the specimens are derived from localities both east and west, as well as north, depending upon the direction of the flow of the land-ice or glaciers on which they were carried, or possibly of the "ice-foot."

American Affinities.

The presence in the collection of *Maclurea magna*, *Receptaculites Neptuni* or *occidentalis* and a new species of this genus, *Favosites gothlandicus*, *Halysites catenulatus*, *Favistella*, &c., all having a peculiar facies and mineral aspect, differing in many respects from the known European series, leads us to the belief that the fossil fauna of Grinnell Land and the north-western shores of Greenland must, on the whole, be correlated or affiliated with that of Arctic America; and although, as might be expected, many of the species, both of the Silurian and Carboniferous groups, are common to both continents, and probably derived from both areas during their life, nevertheless I believe the mass of the fauna belongs to the western hemisphere. The Scotch Silurian fauna has little or no affinity whatever with the Arctic species, neither do the Carboniferous series of Scotland appear to have much affinity with those collected and brought home by the expedition. Their general facies is different, and few species are common to both areas. This is probably what we should expect, looking at the mass of land in Arctic America, and knowing that it is composed chiefly of Lower and Upper Palæozoic rocks. Little, however, if any thing, was known of the geological structure of that great region north of Parry Islands, North Lincoln, Ellesmere Land, and much of Grinnell Land until the present expedition explored the region of Grinnell Land called Grant Land, where a definite coast-line has been determined through the sledge-journey and observations of Lieut. Aldrich, who collected and brought back rock-specimens obtained *in situ* from Cape Columbia, &c., the most northerly land reached. Lieutenant Payer, the historian, and one of the leaders of the Austrian Arctic expedition of 1872–74, assigns to Cape Wien, Petermann Land, nearly the same latitude as to Cape Columbia; but Cape Fligely, the most northern point actually reached by him, is exactly one degree south.

The Carboniferous-limestone fossils brought home by Captain Sir G. Nares (collected by Captain Feilden) is as extensive, as regards species, as any Arctic series yet brought to this country, and from a much higher latitude, all being from north of lat. 81° 6′, chiefly from 82° 40′. The facies is North American and Canadian, although many of the species are British; this, however, we should expect, knowing how widely the Carboniferous-limestone fauna was distributed over the northern hemisphere. The Coral fauna (Actinozoa) is small, only two species occurring in the Carboniferous Limestone, the Silurian Actinozoa being represented by twenty-one genera and twenty-four species, or little more than one species in a genus. The Carboniferous Molluscoida, through the Polyzoa, number four genera and ten species, the individuals being tolerably abundant. The Brachiopoda number eight genera and about twelve species, many of them British. No Lamellibranch, Gasteropod, or Cephalopod has occurred in the Carboniferous series, which is remarkable, and can only be accounted for from the circumstance that the collection represents the rocks in time rather than in space, or is vertical rather than horizontal, owing to the general surface of the country being now covered by snow and ice, so that only the cliffs or highly inclined beds can properly or really be examined and therefore collected from. These remarks apply equally to the smaller collection made by Mr. Hart, of the ship 'Discovery.' Mr. Hart's series consists chiefly of Silurian rocks and fossils obtained at Cape Hilgard, Bessels Bay, and Dobbin Bay.

Contrasting the Silurian collection with that from the Carboniferous Limestone, the species are much more numerous, the Actinozoa greatly so. The Cephalopoda, through the genera *Orthoceras* and *Cyrtoceras*, are tolerably abundant, *but there are no Lamellibranchs* whatever. The Silurian Brachiopoda number about five species, much fewer than would be expected from a comparison with the Upper Silurian facies of Britain, Scandinavia, and America, upon or about the same horizons.

My reference to the belief of a Devonian fauna south of Cape Joseph-Henry is based upon the presence of a few Brachiopoda of peculiar type. The Dana-Bay Carboniferous beds appear repeated by a fault along their strike, and therefore probably not exposing their base. These presumed Devonian fossils were obtained *in situ* from a ravine or torrent-course. The want of other fossils than plant-remains in Heer's Ursa stage precludes comparison here; and as we know that the well-determined horizon of his Ursa-stage flora is at the base of the Carboniferous series, or close of the Devonian epoch, it almost leaves in doubt the position I should assign to these few molluscan remains. Mr. Carruthers, F.R.S., believes that both the Bear-Island and Irish deposits, containing *Lepidodendron* (*Cyclostigma*), were of Devonian age; and I entirely agree with him, knowing at the same time how difficult it is to separate the Upper Devonian from the lowest Carboniferous when one group is conformable to the other.

The important and complete 'Manual of the Natural History, Geology, and Physics of the Arctic regions,' edited by Prof. Rupert Jones, F.R.S.*, gives so complete a list of works and references to all the chief papers relative to Arctic literature, that any bibliography or enumeration of works of reference would here be superfluous. I therefore refer all interested in Polar natural history and geology to the portion of the Manual from page 324 to page 604, where every thing bearing upon these questions is cited.

We have no true evidence of the presence of any Permian rocks within the Polar area, although Toula† (1874–5) refers many of his Polyzoa and Brachiopoda to what he calls Permo-Carboniferous rocks, when the species are common to the two horizons; and he notices the Bell-Sound and Axel-Island species in Spitzbergen; De Koninck also believed that the Polyzoa of Bell Sound were of Permian age. Toula‡ describes species of *Fenestella*, *Polypora*, *Ramipora*, *Phyllopora*, and *Glauconome*§ from this so-called Permo-Carboniferous horizon. Nordenskiöld has also determined that the Spitzbergen true Carboniferous Limestone contains an admixture of species of Polyzoa occurring in other countries only in Permian strata.

No Triassic strata have been detected either in this or any previous expedition; whether, therefore, either the Permian and Trias seas, or both, aided in the denudation of the Carboniferous group, or their sediments were *deposited* and then denuded before the deposition of the Lias, which rests upon the Eglinton-Island Carboniferous Limestone, must still remain an undetermined question. It would

* Manual of the Natural History, Geology, and Physics of Greenland and the neighbouring regions. Prepared for the use of the Arctic Expedition of 1875. Edited by Prof. Rupert Jones, F.R.S. &c. 1875.

† 'Permo-Carb. Fossilien von der West-Küste von Spitzbergen,' pp. 225–264, t. 5–10.

‡ *Vide* notes on bibliography in present paper by R. Etheridge, jun.

§ Proc. Imp. Acad. Sci. Vienna, June 1874, vol. lxx. p. 133.

therefore almost appear that it must have been a continental land, through elevation of the Carboniferous group, until the northern extension of the Liassic seas to these high latitudes. The complete absence (so far as we know) of Permian and Triassic strata in the Parry or Northern archipelago goes far to confirm this. Not a trace of any organic remains younger than the Carboniferous Limestone, and older than the Miocene, has occurred to Feilden and Hart, or to any of the other explorers during their researches in these high latitudes.

SILURIAN.

Kingdom PLANTÆ.

Subkingdom CRYPTOGAMIA.

Genus Buthotrephis, Hall, 1847.

Buthotrephis gracilis, Hall.

Buthotrephis gracilis, Hall, Pal. New York, vol. i. p. 62, t. 21. f. 1.

This may probably be the remains of a marine alga, originally forming filmy impressions or remains on the mud or sand when deposited. Hall's genus *Buthotrephis* may receive our specimen; it was established by him in 1847 to receive such peculiar and dubious markings. *B. gracilis* is the nearest form figured, and closely resembles our single specimen, which was collected by Capt. Feilden at Gould Bay in a fine-grained fissile sandstone. I therefore refer this to *B. gracilis*, Hall, as being almost, if not quite identical.

Loc. Gould Bay, lat. 79° 43′.

Kingdom ANIMALIA.

Class SPONGIDA.

Genus Stromatopora, Goldfuss, 1826.

Amorphous masses of this Sponge (?) occur in the white limestone of Bessels Bay, but so highly crystalline that nearly all traces of character are gone; the thin superimposed concentric layers, and the somewhat twisted, irregular, rugose base, can be made out; polished sections reveal scarcely any or no definite structure, owing to the altered state of the limestone. I have difficulty in clearly detecting (probably from the same cause) any vertical tubuli or oscula, so apparent in the Devonian species, *S. concentrica* &c., in which these tubuli radiate nearly at right angles to the mass, giving it an apparent fibrous structure vertical to the laminæ, and appear as pores upon the external surface. These characters are very well defined in the Devonian form. The genus *Stromatopora* must have abounded in this area, and evidently grew in large parasitic, or incrusting, concentrically laminated masses, equalling in size *Halysites*, *Heliolites*, or *Favosites*. Although polished sections scarcely show the tubuli, still I am not justified in placing these specimens among the Corals or removing them from the Protozoa.

STROMATOPORA CONCENTRICA, Goldf.

Stromatopora concentrica, Goldf. Petref. Germ. vol. i. p. 22, t. 8. f. 5; Lonsd. Murch. Sil. Syst. p. 680, t. 15. f. 31; Hall, Pal. N. Y. vol. ii. p. 136, t. 37. f. 1, t. 37 A. f. 1.

This apparently amorphous sponge (?) is composed of infinitesimally thin concentric layers or laminæ, pierced vertically by cylindrical tubes (tubuli), which when weathered have fibrous structure; considerable space occurs between the imbedded tubuli; the intermediate tissue appears to be solid, but the amorphous and crystalline condition forbids the original structure (and its replacement) being made out. One Devonian species comes very close, and may be taken for the Bessels-Bay form.

Loc. Bessels Bay, lat. 81° 6′, in white limestone.

Genus RECEPTACULITES, Defrance, 1827.

This remarkable Protozoon occurs somewhat abundantly in the Feilden-Nares collection, and is apparently of considerable size. Unfortunately most of the specimens are very fragmentary, all showing the great thickness of the body-wall, but scarcely allowing a correct opinion to be formed as to the dimensions and form, either of the base, summit, or sides, or even if it were a discoidal species. Should our specimens be the basal portions only of the body-wall of a discoidal form, it must have been of gigantic size, and certainly an unknown species. No portions of the specimens show the rounded protuberance or nucleated portion or primitive cell at the base; this would determine somewhat the size to which this species grew, and whether the base was concave or flat. The flat specimens of another form we possess may be only the basal portions of the body-wall of some discoidal species. Some show the base or underside with the point of convergence of the spirally arranged lines or rows of plates of the outer surface. The body-wall of some of the fragments also shows both the internal integument or endorhin, and external or ectorhin, and the closely arranged tubular or spicular skeleton between the walls; the thickness of the skeleton or space between the endorhin and ectorhin, as shown in vertical sections, is considerable, which causes the tubular system to occupy in the body-wall a space of three fourths of an inch. I have no means of knowing the original form our specimens tend to illustrate; but the description of the Canadian species by Messrs. Billings and Salter leads me to believe that the Cape-Frazer specimens are new, neither *R. Neptuni* nor *R. occidentalis* (if they are not conspecific) occurring half the size of our species. *R. Neptuni* and *R. occidentalis* are from the Trenton Limestone (our Caradoc and Bala series). Of the twenty species recorded, eighteen are Lower Silurian; only two (*R. hemisphœricus*, Hall, and *R. subturbinatus*, Hall) appear to be from the Niagara series (Upper Silurian); and one (*R. infundibulum*, Hall) is said to be from the Lower Helderberg group (Devonian). Our specimens are, I believe, from the Lower Silurian series at Cape Frazer and Cape Louis Napoleon, where they are associated with *Maclurea magna*, *Asaphus*, &c. Dr. H. A. Nicholson, to whom I submitted our fragments, also believes them to be portions of a new and large species.

I propose to name it *Receptaculites arcticus*, its occurrence both at Cape Frazer (lat. 79° 45′) and Cape Louis Napoleon (lat. 79° 38′), in Grinnell Land, showing its position so far within the Polar circle.

RECEPTACULITES ARCTICUS, Etheridge.

Body-wall thick; space between the endorhinal and ectorhinal walls nearly an inch in places; tubuli or spicula about six in the space of one inch, and about one eighth of an inch in diameter; interstices large, or nearly equal to the diameter of the tube; ectorhinal surface regularly covered with quadrangular or rhomboidal closely fitting plates, corresponding to the tubuli in places. Circular pores at the angles of the plates in endorhin not seen; tubuli more glass- or spindle-shaped, much more so than in *R. occidentalis*, where they are nearly columnar; the upper ends or terminations of the tubes do not appear to expand so much as in *R. occidentalis* and *R. Neptuni*; the entire wall and tubular system is so very crystalline that more intimate structure cannot be made out; and as the six fragments are not from one individual, accidentally broken in extraction, there is no means of determining the size; but portions of the wall showing the curve either of the base or sides would indicate that it must have been at least 12 inches in diameter.

It is evident that thickness alone of the wall and tubular system must not be insisted upon as a specific character; for in the same specimen the difference in this point is extreme, where the tubes of the basal part are short, especially near the nuclear portion becoming elongated at the sides, thus making the space between the ectorhinal and endorhinal walls of considerable thickness; or in the same specimen the walls will vary in thickness according to the portion examined *.

This species apparently comes from the upper part of the Lower Silurian rocks of Cape Frazer, lat. 79° 45′, and Cape Louis Napoleon, lat. 79° 38′, associated with *Halysites catenulatus*, var. *Feildeni*, *Favosites gothlandicus*, *Maclurea magna*, *Asaphus*, and *Strophomena euglypha*.

Loc. Cape Louis Napoleon, lat. 79° 38′, and Cape Frazer, lat. 79° 45′.

* Polished sections show that the tubuli "radiate from the base, and assume a vertical position in ascending," as in *R. Neptuni*.

RECEPTACULITES OCCIDENTALIS, Salter.

Receptaculites occidentalis, Salter, Geol. Survey of Canada (Canadian Org. Remains), decade 1, p. 45, t. x. figs. 1–7.

R. Neptuni?, Hall, Pal. N. Y. vol. i. p. 68, t. 24. fig. 3.

We have several fragments of this species, enough, however, to determine them to be portions of *R. occidentalis*, Salter. Its discoidal form, quincuncially arranged, spiral, yet concentric lines of cells (engine-turned in pattern) upon the upper surface, and their rhomboidal form on the underside, with round columns having also interstitial spaces nearly equal to their diameter, all tend to correlate this with the Canadian species.

The much more robust or gigantic form which I have named *R. arcticus* cannot be any expanded portion of the side or side walls of this species; the tubuli between the endorhin and ectorhin are also different in shape. Salter remarks that "the thickness of the disk near the centre is but little; but this increases rapidly towards the margin, becoming in some cases half an inch thick at twice the distance from the centre." I refer to this character in case my species *R. arcticus* may be a variety of *R. occidentalis*.

Loc. Cape Louis Napoleon, lat. 79° 38′.

Class HYDROZOA.

Family MONOGRAPTIDÆ.

Genus MONOGRAPTUS, Emmons, 1856.

Rastrites, Salter.

MONOGRAPTUS CONVOLUTUS (His.), var. COPPINGERI, Ether. (Pl. XXV. fig. 1.)

Prionotus convolutus, Hisinger, Leth. Suec. p. 114, t. 35. f. 7.

Graptolithus spiralis, Gein., Leonh. & Bronn's Jahrb. 1842, p. 700, t. x. p. 20–29.

Graptolithus convolutus, Carr. Geol. Mag. vol. v. p. 127, t. 5. f. 1.

Two worn fragments of this subclass and family have been brought home, both unfortunately from the drift of Polaris Bay. Great interest is attached to them on account of the age of the rocks they probably illustrate and characterize. It is the first instance of any Graptolitic form occurring within the polar area; and only one species of *Monograptus* (*Rastrites*), and this from rocks of Caradoc age, seems to be known in America. These fragments appear to be portions of a large *Graptolithus* or *Rastrites*, evidently from fissile shales or thin calcareous bands in some argillo-calcareous rocks.

Although Mr. Carruthers has figured this species in the Geol. Mag. vol. v. t. 5. f. 1, yet I venture to do so again, on account of its occurrence in the Polar collection. Owing to the state of preservation the two spinous processes from the sides of the cell and mouth cannot be seen; but the linear and isolated condition of the cells and other characters are manifest. We do not see the early or first cells, which should be long and slender; but their triangular form in advanced age is well shown.

The specimens occur in fissile, hard, argillaceous limestone.

The high latitude where these fragments were obtained (lat. 81° 40′) tends to confirm the belief that the Llandeilo or Caradoc series is represented so far north, this being partly, if not entirely, confirmed by the presence of large *Maclureæ* and *Receptaculites*, *Helicocotomæ* and *Heliolites*, &c. Barrande obtains *Rastrites* (*Graptolithus*) from his Étage E, or base of the Upper Silurian rocks of Bohemia.

Loc. Thank-God Harbour, lat. 81° 40′ N., in drift.

Class ACTINOZOA.

A large series of sclerodermic corals have been collected both by Captain Feilden and Dr. Coppinger, and many by Mr. Hart and Dr. Moss. The Bessels-Bay, Offley-Island, and Dobbin-Bay species were collected *in situ*. Those from Petermann Fiord, Cape Tyson, and Polaris Bay are all from the drift, talus, and the ice-floe. The two groups Rugosa and Tabulata are fairly balanced as regards number of species, but the chief tabulate coral numerically abundant is *Favosites gothlandicus*; it seems to occur everywhere in the Upper Silurian rocks of the arctic circle. The Tabulata include *Halysites* (the chain-coral) in three varieties, abundant also; *Heliolites* and *Syringopora* a few specimens only; *Alveolites* rare.

Among the Rugosa, we have in the collection *Favistella*, *Zaphrentis*, *Amplexus*, *Cyathophyllum*, *Arachnophyllum*, *Calophyllum*, *Strephodes*, and *Lithostrotion.*

These undoubted reef-forming corals of the Silurian epoch were just as much inhabitants of warm water in southern latitudes at that period as are the Sclerodermata of today in the Indo-Pacific and Atlantic Oceans; and as we know of no compound coral that will exist at a lower temperature than 68° F., and as the surface-waters under the equator in the Pacific have a temperature of 85° F., and in the Atlantic 83°, it seems clear that the range from 68° to 85° F. is best adapted to and not too high for the growth of the reef-making species. We may fairly assume that the temperature of the polar waters during Palæozoic times was as high as that of the Indo-Pacific and Atlantic now, where coral-reefs abound. We are not justified in supposing that the laws regulating oceanic life were very different then from those now existing (in the same groups) under the equator or between the tropics. These corals were forms of life which must have been tropical in habits and requirements. We know nothing of the ancient isotherms or isothermal laws that then, as now, through temperature greatly governed or influenced the distribution of life over the globe, whether upon land or in the sea. All is not due to supposed changes in the direction of the earth's axis or place of the pole. We have yet to learn something of the physical geography of the Northern Hemisphere during Palæozoic times, and the causes that produced the high temperature of the arctic seas during and between the Palæozoic and Miocene periods. We now know that both American and European species occur together in the rocks of King William's Island and Dépôt Bay &c. in Bellot's Strait, and, further north still, up Smith Sound along the shores of Grinnell Land and Greenland as far as 82° 43′.

Favosites gothlandicus and *Halysites catenulatus* seem to be universally distributed through the Silurian rocks of all northern latitudes, abundantly in the polar regions; *Heliolites* also throve, if we may judge from the size of the coralla; and also *Favistella*, which, like *Favosites*, must have flourished at moderate depths. These Actinozoa were associated with *Receptaculites*, *Maclurea*, *Orthoceras*, and Trilobites. Additional proof of the abundance of life is shown by the formation of great deposits of limestone, both Silurian and Carboniferous, equalling in mass those in so-called warmer climates or latitudes.

The Lower Silurian series, through the Chazy, Trenton, Utica, and Cincinnati groups, is represented in the polar fauna by *Maclurea magna*, *M. Logani*, *Ormoceras*, *Favistella*, *Syringopora*, *Halysites*, and Trilobites. The Upper Silurian is represented by the Niagara and Lower Helderberg rocks, containing *Stromatopora*, *Heliolites*, *Zaphrentis*, *Cyathophyllum*, &c., the species of which will be noticed in their respective places. The Cœlenterate fauna, therefore, of the Silurian polar seas, judging from the character and number of specimens collected by the naturalists of the Expedition, must have been a large and prolific one, which, it is hoped, will some day be thoroughly examined.

Group TABULATA.

Genus FAVOSITES, Lamk. 1812.

FAVOSITES GOTHLANDICUS (Fougt).

Corallum gothlandicum, Fougt, Amœn. Acad. 1749, vol. i. p. 106, t. 4. f. 27.

Favosites gothlandica, Lamk. Hist. Nat. vol. ii. p. 206; M.-Edw. & Haime, Mon. Brit. Sil. Corals, Pal. Soc. p. 256, t. 60. f. 1.

Calamopora gothlandica, Goldf. Petref. Germ. vol. i. p. 77, t. 26. f. 3.

Examples of this ubiquitous and typical coral are abundant; indeed it is the commonest coral in the collection, occurring in every locality and in fine preservation, although often too crystalline to show structure. *Favosites gothlandicus* must have been the chief and most abundant coral in the polar Silurian seas—I may say Upper Silurian seas. There is scarcely a single horizon in Britain, from the Caradoc to the Wenlock, in which it does not occur, its place being taken in the Devonian rocks of Europe by *F. Goldfussi*. These two species, belonging to the massive type, abound in their respective formations—*F. gothlandicus* in the Silurian deposits everywhere, and *F. Goldfussi* in the English, Rhenish, French, and Belgian Devonians.

The ramose forms are more widely distributed, but are few in the polar area. Possibly *F. alveolaris* occurs also; I have recorded it from one locality (Washington-Irving Island), but have difficulty in distinguishing the pores in the angles of the corallites. We record *F. gothlandicus* from twelve or fourteen different localities, and have nearly forty specimens of all sizes and habit of growth, some of the large circular convex masses with complete wrinkled epithecal bases being of considerable diameter. The individual specimens vary both as regards the width or size of the corallites (columns) and in the distance or spaces between the tabulæ.

I have not observed the variety *F. Troostii* in Captain Feilden's series. Although a common American form or variety of *F. gothlandicus*, it is distinguishable by usually having three rows of pores and longitudinal lines on the faces of the tubes or corallites and very close-set tabulæ; but so variable are the forms in *F. gothlandicus* that every shade of difference can be detected, and may be made the basis of a new species. It must be admitted that no more variable coral exists; and no rule can be given for the size of the cell-opening, number of pores, or number and distance of the tabulæ in a given vertical space. Again, the pores do not always possess the elevated rim or border. Little or no trace of the radiating septa or their spinose or tubercular representatives can be detected in the specimens, owing to the metamorphism of the limestones. Hall's *F. niagarensis* appears to be only a variety of *F. gothlandicus*. *Astrocerium*, Hall, and *Emmonsia*, Edw. & Haime, seem to be identical with *Favosites*. No less than eleven of the twenty-six species known are American, and four arctic, viz. *F. megastomus*, *F. perplexus*. *F. alveolaris*, and *F. gothlandicus*.

Loc. Washington-Irving Island, Polaris Bay, Cape Frazer, Bessels Bay, Offley Island, Dobbin Bay, Cape Tyson, &c., *in situ*. Common also in the drift.

FAVOSITES ALVEOLARIS (Goldf.).

Calamopora alveolaris, Goldf. Petr. Germ. vol. i. t. 26. f. 1.

Favosites aspera, M.-Edw. & Haime, Mon. Brit. Foss. Corals, Pal. Soc. p. 257, t. 60. f. 3.

One or two specimens of this coral in perfect condition have been received from the Wenlock rocks of Washington-Irving Island; it does not seem to occur elsewhere in the Arctic region. Hall identified the species in the Onondaga group, our Upper Wenlock, in 1843; but it does not seem to have been recorded from East or West Canada, either under this name or that of *F. asper*, D'Orb. *F. multipora*, Lonsdale, may be another form and name for this coral.

These Favositæ are troublesome species to determine unless the coralla are sufficiently well preserved to allow of sections being made for determination. *Favosites alveolaris*, like *F. gothlandicus*, has a wide range in time as well as in space; it is found in the Lower and Upper Silurian series, ranging from the Caradoc to the Ludlow rocks inclusive, not only in the British Islands, but in Bohemia, Scandinavia, and Russia. It is now recorded from the Washington-Irving beds (lat. 79° 34′).

Favosites, sp.

One specimen of a globose mass resembling an *Alveolites* is among the other difficult things in the collection to determine; but the walls of the corallites are much thicker and the calices more regular than in *Alveolites*. The tabulæ are remote and faintly developed, and the walls perforated apparently in a single row.

Sp. char. Corallum massive, convex, growing in layers concentrically arranged; base concentrically rugose; calices small, polygonal or apparently six-sided; walls of corallites thick; mural foramina or perforations in single lines; no septa visible. Tabulæ thin, distant, and alternating with those of the adjoining corallites.

Loc. Cape Louis Napoleon, lat. 79° 38′.

Genus Heliolites, Dana, 1846.

Heliolites megastomus (M'Coy).

Palæopora megastoma, M'Coy, Brit. Pal. Foss. p. 16, t. 1 c. f. 4.
Parites megastoma, M'Coy, Sil. Foss. Irel. p. 62, t. 4. f. 9.
Heliolites macrostylus, Hall, Pal. N. Y. vol. ii. p. 135, t. 36 a. f. 2.
H. megastoma, Edw. & Haime, Mon. Brit. Foss. Corals, Pal. Soc. p. 251. t. 58. fig. 2.

The slight development of the cœnenchyma and large closely-set corallites (as compared with other species of *Heliolites*) leads me to believe that this is M'Coy's species. The corallites are separated by reticulate cœnenchyma and possess rather thick tabulæ. Hall records this species from the Niagara group under the name of *Heliolites macrostylus* (Pal. N. Y. vol. ii. p. 135, t. 36 a. f. 2), and it appears also to be the coral referred to by M'Coy under the name of *Palæopora megastoma* (Brit. Pal. Foss. p. 16, t. 1 c. f. 4). This coral has a wide distribution, ranging from Britain to North America. All the Petermann-Fiord specimens are glacier-borne from the east.

Unfortunately the two specimens obtained were not found *in situ*, but were taken by Dr. Coppinger from the south-west shore of Petermann Fiord on No. 1 glacier, occurring in the talus with other fossils. They are portions of a hemispherical mass or corallum.

A *Pentamerus*, allied to *P. Verneuili*, and *Favosites gothlandicus* were collected at the same spot. These, like the Bessels-Bay and Offley-Island species, are Greenland forms, and derived either from rocks at the sides of glaciers or brought down from the interior of the country on the glaciers.

Loc. Petermann Fiord, lat. 81°.

Genus Alveolites, Lamk. 1801.

Alveolites, sp.

Two specimens of an *Alveolites* occur amongst the coral-fauna, one from Cape Frazer and the other from Cape Louis Napoleon, east of Dobbin Bay in Grinnell Land. Considering the number of known species in this genus in the Silurian and Devonian rocks of America and Europe (about thirty), it is singular that we have no better representatives than the two recorded.

I cannot refer them to any British species, owing to their bad state of preservation.

Loc. Cape Frazer, lat. 79° 45′, and Cape Louis Napoleon, lat. 79° 38′.

Genus Halysites, Fischer, 1813.

Catenipora, Lamarck, 1816.

Halysites catenulatus (Linn.).

Tubipora catenularia, Linn. Syst. Nat. 12th ed. vol. i. p. 1270.

Halysites catenularia, M.-Edw. & Haime, Mon. Brit. Foss. Corals, Pal. Soc. p. 270, t. 64. f. 1.

Catenipora escharoides, Lamk. Hist. Nat. vol. ii. p. 207.

Our specimens are, without doubt, the true well-known "chain-coral" whose distribution through the Lower Palæozoic rocks is universal both in time and space (Llandeilo to the Ludlow rocks). The specimens resemble those of the Upper Silurian of Britain, and probably belong to the Wenlock group, and are associated with forms whose facies are of that series. The specimens collected by Mr. Hart from Dobbin Bay and Cape Hilgard appear to be true *H. catenulatus.*

There seems, however, to be considerable difference in some of the forms of *Halysites* brought home by the naturalists of the 'Alert' and 'Discovery;' if not specifically different, they should be noticed and recorded as varieties. The form *Catenipora labyrinthica*, Goldf., Petr. Germ. vol. i. p. 75, t. 25. f. 5, would answer to those having large interspaces or reticulations between the vertical corallites. I know it is scarcely possible to separate the extreme varieties *C. escharoides*, De Blainville, and *C. labyrinthica*, Goldfuss, as recorded and figured by Goldfuss; but as we appear to have them in the collection, it is necessary to draw attention to their extreme variation. No less than six species are recorded by the American and Canadian palæontologists.

Loc. Cape Hilgard, lat. 79° 41′; Cape Frazer, lat. 79° 45′; and Dobbin Bay, lat. 79° 40′. Upper Silurian.

Halysites catenulatus, var. Feildeni, Eth. (Pl. XXVIII. fig. 1.)

Corallum massive; base concentrically and irregularly rugose; the corallites radiate horizontally from the centre of the base (resembling in habit those of *Favosites*), and then assume the vertical growth when at or near the outer edge of the corallum; tabulæ thick and very closely arranged, which, on weathering, gives a very rugose appearance to the corallites; reticulations between the chain-like pattern on the upper surface of the corallum very small and polygonal; calices either elliptical or polygonal; and frequently only two or three corallites occur in the space or vertical wall constituting the reticulations.

The habit of this variety differs so much from that of the common form of *H. catenulatus*, or the more ramifying and taller-growing variety, that I am justified in giving it the varietal name. As an extreme variety it deserves recognition and description; I therefore name it after the indefatigable naturalist to the Expedition. Dana notices Hall's species *H. gracilis* from the Hudson-river group, Green Bay, Wisconsin, from a lower horizon than Captain Feilden's specimen. *H. catenulatus*, var. *Feildeni*, differs from the true *H. catenulatus*, Linn., from Cape Frazer and Dobbin Bay, by the extreme smallness of the reticulations, very closely arranged tabulæ, and compact habit of growth. *H. escharoides* (De Blainv.) is its nearest ally.

Loc. Cape Hilgard, lat. 79° 41′.

Halysites catenulatus, var. Harti, Eth. (Pl. XXVIII. fig. 2.)

This form differs considerably from the usual habit of *Halysites catenulatus*, the chain-like rows of corallites constituting the corallum being very much more extended or enclosing larger interspaces or areas, and closely resembling the variety *Catenipora labyrinthica* of Goldfuss. The epitheca, too, and the walls are more coarsely rugose, the striæ being coarser than in *H. catenulatus* proper; this does not appear to be due to age only; the character is well shown in Goldfuss's figure (Petr. Germ. p. 75, t. 25. f. 5). Further the series of corallites in the winding loops are much more numerous than in the recognized forms of *H. catenulatus*. The whole corallum is also more robust in habit, and must have been of large dimensions vertically and laterally. I figure this amongst other variable species in the collection, as being a very aberrant form of *Halysites*.

Loc. Cape Frazer, lat. 79° 45′.

Genus Syringopora, Goldfuss, 1826.

Syringopora parallela, Eth. (Pl. XXVI. fig. 1.)

We have only one specimen of this genus; it much resembles *S. geniculata*, Phill., from our Carboniferous rocks. The corallites are cylindrical, tall, slender, nearly parallel, and closely arranged; the walls are covered by a thick epitheca; the horizontal connecting tubes rather numerous or closely set, although certainly not so much so as in *S. geniculata*; neither is it our Silurian species *S. bifurcata*, Lonsd., being more delicate in habit; and the corallites are more densely packed and more regularly parallel in their upward growth than in *S. reticulata*, although it much resembles that species. Weathered specimens show the infundibuliform tabulæ. Little geniculation takes place at the origin of the transverse or connecting tubes, which certainly are more remote than in *S. reticulata*, His. It is not the so-called *S. multicaulis* of Hall, from the Niagara group, which is described as having from fourteen to sixteen rays. Neither is it Billings's *S. Maclurei* or var. *elegans* (to both of which there is resemblance) from the Corniferous Limestone of Ohio.

Syringoporæ much resemble each other in all the older Palæozoic rocks. Our species I believe to be new, and therefore venture to figure it.

Loc. Dobbin Bay, lat. 79° 40′.

Group Rugosa.

Genus Cyathophyllum.

Cyathophyllum articulatum (Wahlenb.).

Madreporites articulatus, Wahlenberg, Nov. Act. Soc. Upsal. vol. viii. p. 97.

Cyathophyllum articulatum, M.-Edw. & Haime, Mon. Brit. Sil. Corals, Pal. Soc. p. 282, t. 67. f. 1.

Three specimens of this branching cyathophylloid coral come from the Upper Silurian rocks of Dobbin Bay. They agree in every particular with Wahlenberg's species *C. articulatum*. In *C. cæspitosum* of Lonsdale the corallum is fasciculate and the corallites closely arranged. The accretion-ridges are not quite so highly developed as in the British species; this, however, depends much upon the state of preservation of the corallites. Compared with our Wenlock forms no difference can be detected.

This coral was collected by Mr. Hart at Cape Hilgard, lat. 79° 41′, and by Dr. Coppinger in Dobbin Bay, lat. 79° 40′, in the Upper Silurian series.

Genus Chonophyllum, M.-Edw. & Haime, 1850.

Chonophyllum, sp. allied to magnificum, Billings, Canadian Journal, 1859; E. Rominger, Geol. Surv. Lower Peninsula, Michigan, 1876, p. 116, t. 43. (Pl. XXVIII. fig. 3.)

Three portions of the calice of what must have been a very large coral, from 3 to 4 inches in diameter, occur in the collection.

On comparison with the figure of this species by E. Rominger (Geol. Lower Peninsula, Michigan, 1876, p. 116, t. 43), I have no doubt that these calicular pieces should be referred to *Chonophyllum magnificum*. The very coarse and equal septa and small but deep somatic cavity agree in every particular with this Upper Helderberg species.

Sp. char. Corallum conical; calice greatly expanded or explanate, flattened towards the edge; septa equal, linear, about ninety in number, thick or broad near the circumference of the corallite. Our specimens do not show the centre or somatic cavity of the calice; probably the septa did unite to form a central fascicle or columella. Diameter of the calice 3 inches. The height of our specimens we are not able to determine, only the expanded calice being left; probably it was about the same as *Omphyma* or *Ptychophyllum.*

Loc. Dobbin Bay, lat. 79° 40′. Upper Silurian. Collected by Dr. Coppinger.

Genus Calophyllum, Dana, 1848.

Calophyllum phragmoceras, Salter.

Calophyllum phragmoceras, Salt., Sutherland's Journ. vol. ii. p. ccxxx, t. 6. f. 4.

I refer this specimen to *Calophyllum phragmoceras*, Salt. The corallum occurs in clusters composed of conical corallites, which rapidly enlarge at the calice, and often measure an inch in diameter. The tabulæ are closely set and slightly concave; the edges of the calices are not crenulated, but have very short thin lamellæ or septa; the costæ equal the septal laminæ in number, are coarsely or strongly marked and interrupted at intervals by transverse slightly indented lines. Our specimen shows no evidence of calicular gemmation within the edge of the older corallites.

This coral resembles in appearance externally a compound *Zaphrentis*, owing to the somewhat expanded nature of the calice and habit of growth. The surface or epitheca is commonly striated longitudinally, and intermittently constricted like *Zaphrentis*. The tabulæ I am not able to see, and therefore fail to notice the resemblance to *Amplexus* described by Salter, *loc. cit.* Dr. Sutherland's specimens came from Wellington Channel.

Loc. Cape Hilgard, lat. 79° 41′.

Genus Arachnophyllum, Dana, 1846.

Arachnophyllum Richardsoni, Salter.

Arachnophyllum Richardsoni, Salter, Sutherland's Journ. vol. ii. p. ccxxxii, t. 6. f. 10.

Mr. Hart, of the 'Discovery,' obtained this fine species at Cape Hilgard; it was first discovered by Dr. Sutherland at Point Eden, south side of Baring Bay, lat. 76° 20′. It is well figured in the volume above mentioned. The range of this species in space is considerable, Mr. Hart having obtained his specimen at Cape Hilgard, in lat. 79° 40′, on the east coast of Grinnell Land, 3° 20′ further north than Dr. Sutherland. *Strephodes Austini*, Salter, and *Calophyllum phragmoceras*, Salter, appear to have been collected with *Arachnophyllum Richardsoni* at Cape Hilgard, thus showing that the Baring-Bay beds must be upon the same horizon as those of Cape Hilgard, 3° further north.

Mr. Salter described and figured what appears to be this coral from the Sutherland collection, *loc. cit.* The genus closely resembles *Phillipsastræa*; but the obtuse, flattened, or depressed polygonal calices with numerous fine radiating lamellæ, which meet or are continuous with those of adjoining corallites, separate it from that genus. The absence of solid partitions or boundary-walls removes it from the compound *Strephodes*, and it differs from *Sarcinula* in not having the distinct septate corallites. Our specimen is a wavy expanded mass; the corallites circular, small, and steeply edged, irregularly scattered over the surface, with well-defined styliform columellæ or axes; the margins of the calices are slightly elevated above the plane of the anastomosing lamellæ, resembling some *Isastrææ*. Diameter of cells about 1 line. Base not seen; probably it was concentrically rugose.

Loc. Cape Hilgard, lat. 79° 41′.

Genus Favistella, Hall, 1847.

Favistella reticulata, Salter.

Favistella reticulata, Salter, Sutherland's Journ. vol. ii. p. ccxxix, t. 6. f. 2.

The hexagonal cells, with rather thick walls and wavy tabulæ, and the alternately long and short septa or lamellæ, reaching about halfway from the wall to the centre of the calice, clearly define this species.

Dr. Sutherland collected his specimens at Cape Riley, Barrow's Straits, in lat. 74° 40′. Captain Feilden obtained his at Franklin-Pierce Bay, Walrus Island, and Cape Hilgard, lat. 79° 41′, 5° further north than Dr. Sutherland.

Loc. Franklin-Pierce Bay, lat. 79° 25′, and Cape Hilgard, lat. 79° 41′.

Favistella Franklini, Salter.

Favistella Franklini, Salter, Sutherland's Journ. vol. ii. p. ccxxxi, t. 6. f. 3.

This must have been a large coral, composed of elongated polygonal tubes mostly agreeing in size, and of equal diameter on the surface. The septa or lamellæ are almost obsolete; tabulæ very closely arranged and not quite horizontal.

We possess only a fragment or two, but enough to distinguish them to be *F. Franklini*, Salter, as figured in the above reference.

Loc. Dobbin Bay and Cape Hilgard, lat. 79° 41′.

Genus Sarcinula, Lamk. 1816.

Sarcinula organum, Lamk.

Sarcinula organum, Lamk. Hist. Nat. vol. ii. p. 223; Goldfuss, Petr. Germ. vol. i. p. 73, t. 37. f. 10.

At first sight this specimen resembles *Favistella*, especially in the vertical section; but the calices are round or slightly subangular when polished, certainly not polygonal as in *Favistella*; again, there do not appear to be any interstitial tubes, showing that development took place through lateral fission. Indistinctly the corallites appear to have two walls, as in *Acervularia*, although the crystalline condition of the cellular tissue quite prevents this being determined. A large and loosely twisted columella occurs in the centre, arising from the meeting of the septa, of which there are twenty. Tabulæ numerous and closely set, giving a highly reticulate character to the corallites.

Loc. Cape Hilgard, lat. 79° 41′.

SARCINULA, var. of ORGANUM.

A single specimen only of this variety occurs; it resembles *Lithostrotion irregulare* or *Martini* in its somewhat irregular growth; but the corallites are even less straight than in those species, and are more reticulate in structure.

Loc. Cape Hilgard, lat. 79° 41′.

Genus STREPHODES.

STREPHODES AUSTINI, Salter.

Strephodes Austini, Salter, Sutherland's Journ. vol. ii. p. ccxxx, t. 6. f. 6.

I refer this single specimen also to the above species. M'Coy was inclined to refer Dr. Sutherland's specimens to *Clisiophyllum*. Owing to the twisted condition of the columellar lamellæ, our specimen very feebly shows the twisting of the septa in the centre of the calices; they certainly were never so columnar or tent-like as in typical specimens of *Clisiophyllum*. I, however, can only refer Mr. Hart's specimen to the above species, with which it agrees in every particular. It was collected by Mr. Hart from the Upper Silurian beds at Cape Hilgard, lat. 79° 41′.

Genus ZAPHRENTIS, Rafinesque, 1820.

ZAPHRENTIS, sp.

This genus is unknown in Britain from the Silurian rocks. M'Coy records *Caninia* from the Wenlock Limestone near Wenlock; but the genus as restricted is chiefly confined, in Britain, to the Carboniferous Limestone. In North America, however, six or eight species occur in the Upper Silurian series.

The four specimens we have seem to me to be *Zaphrentis*, but their condition is so crystalline that hardly any septa can be detected; the costa are coarse and well preserved, the costal lines answering to the number of septa.

Polished sections afford no real aid, owing to the complete obliteration of the interior of the calices; but there can be no doubt as to the genus being well represented in the Polar seas. We now have it from the Upper Silurian of Offley Island, Bessels Bay, and Dobbin Bay, lat. 79° 41′.

ZAPHRENTIS OFFLEYENSIS, Eth. (Pl. XXVI. figs. 2, 2*a*.)

Corallum gently curved, pediculate, about an inch in diameter; calice slightly oval; septa numerous (forty-eight), half of which do not reach far into the calice; chief septa thick or strongly developed; the costæ appear to equal the septa in number; constrictions in the corallum numerous, becoming stronger with age; septal fossulæ not determinable.

The species are so numerous in this widely distributed genus, and they resemble each other so closely, that it is almost impossible to compare one with another, especially when widely separated in space; and their habit and growth so depend upon the circumstances under which they lived that, homotaxially or in time-horizons, little can be depended upon for determination.

I therefore name these after the locality where found (Offley Island), by way of drawing attention to the distribution of the genus. Only portions of two corallites occur, and the coral is so crystalline that most of its structure is obliterated.

Loc. Offley Island, lat. 81° 16′.

ZAPHRENTIS, sp. allied to Z. PROLIFICA, Billings, *fide* Rominger, Geol. Surv. of Michigan, vol. iii. 1876, p. 147, t. 53 (upper figures).

Of this stunted species we have two specimens; they both resemble *Z. Enniskilleni*, M.-Edw. & Haime, from the Carboniferous Limestone of Britain. The entire calice or septal system is not seen on either specimen; but the figures and description given by Rominger (*loc. cit.*) answer to Billings's species, and they are undoubted *Zaphrentes*. The corallum is turbinate, short, and pediculate, with an expanded calice; costæ coarse. Owing to the calices not being perfect, the number of septa remains unknown. Our specimens measure 1 inch and 1½ inch in height, and about 1 inch in diameter. Billings's species, *Z. prolifica*, occurs in the Corniferous Limestone of Port Colborne, the Upper Helderberg Limestone of Michigan, &c.

Loc. Dobbin Bay, lat. 79° 40′.

ZAPHRENTIS, sp. (Pl. XXVIII. fig. 5.)

This is the only single or simple coral found at Bessels Bay. It occurs in the crystalline white limestone which abounds with *Favosites gothlandicus*; but the same beds evidently occur at Offley Island and contain other species. I am not sure that this may not be a *Clisiophyllum*. In polished sections there appears to be a twisted columella; but the calice is so crystalline that the relation of the septal system at the edge of the calice cannot be well traced to the columella.

Sp. char. Corallum oval or compressed, nearly straight, tall, roundly constricted at intervals; costæ numerous, delicate, or more thread-like than in most *Zaphrentes*; columella (if any) slightly twisted; septa about sixty, intermediate septa not seen, nearly all structure being obliterated.

Loc. Bessels Bay, 81° 6′.

Genus Amplexus, Sowerby, 1802.

Amplexus Feildeni, Ether. (Pl. XXVI. fig. 3.)

This single incomplete portion of a large *Amplexus* is, I doubt not, new, and must have been of considerable height or length, judging from the diameter of the corallum left, which measures more than 1½ inch.

Sp. char. Corallum tall, straight, constricted at regular intervals, or where the tabular floors cross the corallum; septa numerous, equally developed, rather wide apart and marginal; chief septa about thirty-six in number; but I cannot be sure that there are not alternately smaller, shorter, or intermediate septa; costæ numerous, double the number (seventy-two) of chief septa, thus rendering it probable that there are seventy-two septa (thirty-six primary and thirty-six secondary, comprising two cycles); tabulæ distant, very slightly concave and smooth, not always of the same size or occupying the same area. Now and then the septa on some of the tabulæ encroach upon the planes, and thus give them a smaller area; septal fossula not seen: we have not, perhaps, the last tabulæ, in which it is usually more distinct or better preserved.

This coral is remarkable for its size, the distance between the tabulæ, the well-developed costæ, the coarseness of the chief septa, and the reed-like habit of its growth, much resembling in appearance many *Calamites* from the Coal-Measures, especially *C. approximatus*.

Many specimens of *A. coralloides*, Sow., are as large as our *A. Feildeni*, but differ much in the arrangement and development of the septa upon the tabulæ near the edge of the corallite. De Koninck, in his 'Nouvelles Recherches sur les Animaux Fossiles du Terrain Carbonifère de Belgique,' p. 65, t. 5. f. 1, 1872, figures two specimens of *A. coralloides* equal to, and another double the diameter of, our species; but the thin disk-like condition of the tabular system entirely removes *A. Feildeni* from *A. coralloides*. Numerous as are the species in the Carboniferous rocks of Belgium, still none agrees with our species.

This and the following species were collected by Dr. Coppinger, of the 'Alert.'

Loc. Offley Island, lat. 81° 16′. Upper Silurian.

Amplexus, sp. (Pl. XXVI. fig. 4.)

I cannot be sure that this is *Amplexus Feildeni*, although it might pass for a smaller individual. It is of much less diameter, and the costæ do not quite agree with those of that species; the septa are coarser for its size, and range further in upon the tabulæ, which, as in *Amplexus Feildeni*, are also far apart.

I am not justified in making it a new species. I figure it, however, to draw attention to the form.

Loc. Offley Island, lat. 81° 16′. Upper Silurian. Collected by Dr. Coppinger.

Class ECHINODERMATA.

Many of the limestones are literally made up of Crinoidal remains, chiefly stem-ossicula, yet in no instance has a really determinable specimen been obtained. We have portions of the stems of *Crotalocrinus* somewhat abundantly, but the limestones are so crystalline that all structure is obliterated.

The white limestones of Bessels Bay contain *Stromatopora* and a *Lithostrotion* associated with these crinoidal fragments. No statuary marble is whiter than these perishable limestones, which readily fall to pieces upon handling.

Loc. Bessels Bay, lat. 81° 6′.

Class CRUSTACEA.

Order TRILOBITA.

Genus Bronteus, Goldfuss, 1843.

Bronteus, sp., allied to B. hibernicus, Portlock, Geol. Rep. t. 5. f. 8.

Half only of the pygidium of this species occurs in the white limestone of Bessels Bay; it is much larger than the caudal shield of *Bronteus flabellifer* from the Middle Devonian of South Devon or the Eifel form. It was collected by Mr. Hart, of the ship 'Discovery,' from the white or pale-coloured limestones of the bay above mentioned. Comparison with *Bronteus hibernicus*, Portlock, Geological Report, t. 5. f. 8, shows great resemblance; but the single caudal somite, from which spring the fan-shaped pleuræ, is wanting, and only half the pleuræ are left. I have no alternative, however, but to refer it to that species for close comparison. Four species have been described from America—one from Nova Scotia, one from Anticosti Island, and two from New-York State.

Loc. Bessels Bay, lat. 81° 6′. Upper Silurian.

Bronteus flabellifer, Goldf.

Brontes flabellifer, Goldf. Nova Acta Acad. Cæs. Leop. Nat.-Cur. vol. xix. pt. i. p. 361, t. 33. f. 3.

Bronteus flabellifer, Phill. Pal. Foss. Dev. & Cornw. p. 131, t. 57. f. 254.

I have no doubt about this single pygidium belonging to the above species; there is no difference whatever between it and our Middle Devonian *Bronteus flabellifer*. Mr. Hart collected this well-known species from Bessels Bay, associated with the series of Upper Silurian fossils found at that place; it needs no further notice. I believe, however, it is now recorded for the first time from the Upper Silurian rocks, never hitherto having been found below the *Stringocephalus* or Middle-Devonian series of Britain and Belgium.

Loc. Bessels Bay, lat. 81° 6′.

Genus Asaphus, Brongniart, 1822.

Asaphus, sp., like A. tyrannus, Murch. Sil. Syst. t. 24, t. 25. f. 1.

Asaphus tyrannus, Salter, Monogr. Sil. Trilobites, Pal. Soc. p. 149, t. 21, t. 22. f. 5–12.

Unfortunately only the pygidium or caudal shield has been left upon a slab of limestone; but no doubts are entertained as to the genus, although only so small a specimen. It agrees in every respect with the pygidia of small or young forms of *Asaphus tyrannus* and *Asaphus Powisii*: the axis may be narrower than usual in those species, being more uniform in width or diameter; but the pleuræ and broad caudal fascia all tend to convince me that it is closely allied to *Asaphus tyrannus*, although with us this is a Llandeilo form; indeed in Britain no species of *Asaphus* is known in the Upper Silurian rocks. There seems much doubt as to the horizon at Cape Louis Napoleon from which some fossils come; we certainly have Lower and Upper Silurian species in the series from this locality.

Asaphus marginalis, Hall, Pal. N. Y. vol. i. p. 24, t. 4. fig. 5, resembles this only in the narrowness of its caudal axis.

Loc. Cape Louis Napoleon, 79° 38′. From Upper Silurian.

Genus Calymene, Brongniart, 1822.

Calymene, sp.

? *Calymene senaria*, Conrad, Ann. Geol. Report, New York, 1841, p. 49; Hall, Pal. New York, vol. i. p. 238, t. 64. f. 3, *a–n*.

The cephalic portion of this species is wanting, and also much of the caudal shield; nevertheless I think I am right in referring it to the *Calymene senaria* of Conrad. Hall obtained his specimen from the Trenton series; it is very closely allied to our *Calymene Blumenbachii*, or one of its many varieties; twelve thoracic somites are distinctly preserved. The faceted pleuræ cannot satisfactorily be made out, the specimen being much weathered, and none of the cephalic portion remains. The figure and description given by Hall (*loc. cit.*) for the American species agree better with our specimen than that given by Salter in the Palæontographical Society's Memoirs, t. 9. figs. 6–11. Many forms of the variable *Calymene Blumenbachii* may be mistaken for the specimen I have referred to Conrad's species.

Loc. Dobbin Bay, lat. 79° 40′; furnishing another instance of the mingled condition or character of the series from this locality.

Calymene, sp.

Six thoracic segments with axis and pleuræ of some species of *Calymene* occur in the Silurian Limestones of Hayes Point, lat. 79° 42′: fragments of some unknown Crustacean (?) are associated with it; these will be referred to in their places. If not *Calymene*, these somites may belong to *Encrinurus lævis*; they much resemble each other in all parts but the cephalic region. See Journal of Voyage in Baffin's Bay and Barrow's Straits (Penny); Sutherland's Journal of Capt. Penny's Voyage to Wellington Channel, 1850–51, vol. ii. p. ccxxi, t. 5. f. 14, for *Encrinurus*.

Loc. Hayes Point, lat. 79° 42′.

Genus Encrinurus, Emmerich, 1844.

Encrinurus lævis (Angelin.).

Cryptonymus lævis, Angelin, Palæontologia Scand. part 1, fasc. 1, p. 4, t. 4. fig. 10.

Encrinurus lævis, Salt. Sutherland's Journal, vol. ii. p. ccxxi, t. 5. f. 14.

This genus, and probably the species now in the Arctic collection, was obtained somewhat abundantly by Dr. Sutherland during the Expedition under Captain W. Penny, 1850–51, associated with *Pentameri* from Cornwallis Island; the only species of *Pentamerus* then brought home was *Pentamerus conchidium*, Dalm., a form much resembling our *Pentamerus Knightii*, and similar to Greenland specimens. I have compared the imperfect remains from Dobbin Bay, collected by Dr. Coppinger and Captain Feilden, with those brought home by Dr. Sutherland, which Mr. Salter referred to *Cryptonymus lævis*, Angelin, and cannot detect any difference. The cephalic portion (glabella and cheeks) very closely resembles our *Encrinurus variolaris* (Brongn.); the pygidium, however, differs essentially from the same part in that species, being more massive, and the segments of the axis not ornamented with tubercles.

I cannot see any difference between the several imperfect portions in our collection; I therefore refer them all to Angelin's species.

Dr. Sutherland's specimens were found at Cape Riley, on Griffith's Island, Cornwallis, Seal, and Dundas Islands; it appears to have been abundant at Griffith's Island, lat. 75°.

Dr. Coppinger collected his specimens at Dobbin Bay, lat. 79° 40′, associated with *Receptaculites*, *Favistella*, *Halysites*, and *Favosites gothlandicus*.

Genus Proetus, Steininger, 1830.

Proetus, sp.

One specimen, comprising parts of five thoracic somites and the pygidium, is all we have of what I believe to be the genus *Proetus*; it occurs in a dark-grey earthy limestone from Cape Leidy, lat. 79° 38′. I can do no more than record this form as occurring in the collection.

Loc. Cape Leidy, lat. 79° 38′. From Upper Silurian.

Crustacean Remains.

A number of specimens were collected by Captain Feilden at Cape Louis Napoleon which have every appearance of being portions of some large crustacean, probably fragments of a gigantic *Illænus* or *Isotelus*. Here and there on the specimens there are slightly wavy or undulating lines or striæ, such as occur upon the shelly carapace of the *Illæni* and *Asaphi*, yet upon microscopical examination no definite structure can be determined. On one or two of the rock specimens we have portions of what appear to be the carapace of undoubted *Illæni* (rostral shield and posterior spines); and the greatly compressed state of the specimens, be they what they may, is clearly shown in section; but being crystalline, their structure is obliterated. Sections of the axes and pleuræ of *Pterygoti* and *Eurypteri* would have much the same appearance as the compressed and flattened parts of what appear to be segments; indeed dismembered parts of the Merostomata would probably suggest an explanation of their history. Remains of *Eurypteri* are abundant in the Waterlime group (Upper Silurian) of New-York State and Oneida county, lying beneath the Lower Helderberg group. I have suggested the Merostomata as being the most likely group to comprise these singular sections. *Platynotus* and *Homalonotus* amongst the Trilobita, when broken up, may equally suggest their nature. I have submitted these fragments to crustaceologists; but no true light has been thrown upon them. I was disposed to regard them as portions of the plant called *Palæophycus*; but the structure of the outer edges of the compressed bodies, when subjected to microscopical examination, forbids that: they are still left for determination.

Loc. Cape Louis Napoleon, lat. 79° 38′.

Class BRACHIOPODA.

Comparatively few Brachiopoda occur in the Silurian series collected by the naturalists of the Expedition; only five out of fifteen families and forty-seven genera are represented, which, considering the number of specimens of shelly fossiliferous limestones (many crowded with species), is singular, this class being abundant in the Upper Silurian rocks of Britain, Scandinavia, and Spitzbergen. No *Lingulæ*, *Craniæ*, *Discinæ*, or *Terebratulæ* have been detected. Species of the genera *Anastrophia*, *Pentamerus*, *Chonetes*, *Rhynchonella*, *Atrypa*, *Meristella*, and *Strophomena* occur, but only one or two species in each genus. America yields no less than 1120 species; *Atrypa*, *Orthis*, *Rhynchonella*, and *Strophomena*, as with us, predominating. Looking at the collection of Corals, Polyzoa, Gasteropoda, &c., we should have expected on bathymetrical grounds a larger assemblage of associated Brachiopoda.

The Carboniferous fossils brought home are mostly of this class and a few Polyzoa, the two families Productidæ and Spiriferidæ being fairly represented. Deep-sea forms (non-articulate genera) are absent in both the Silurian and Carboniferous rocks; but doubtless the difficulty in collecting from ice-covered horizontal areas prevented their being observed in any quantity. It is, however, evident that a large Brachiopod fauna exists both in the Upper Silurian and Carboniferous series as far north as 82° 43′.

Feilden Isthmus abounds in Carboniferous species; a rich harvest could be obtained from this locality, and doubtless the Devonian forms could be largely added to from the same area.

Genus Pentamerus, Sowerby, 1813.

Pentameri were brought home by Dr. Sutherland from Wellington Channel, and found by him at Cornwallis Island. Salter referred the specimens to *Pentamerus conchidium* (Dalm.), the same shell being noticed by DeVerneuil in Geol. Russ. t. 1. f. 2. This shell much resembles the well-known *Pentamerus Knightii* of the Aymestry Limestone.

The Coppinger collection from Offley Island and Bessels Bay contains two, if not three, species certainly not referable to Dalman's *Pentamerus conchidium*. One form is allied to the *Pentamerus galeatus*, Dalm., of our Upper Silurian rocks, but is not so tumid, and is evidently a smoother species.

Dr. Coppinger also collected at Petermann Fiord, in talus on the south-west glacier, on the floe, and under cliffs on the north-east shore of the Fiord, numerous specimens allied to *Pentamerus* or *Anastrophia Verneuili*, Hall, from the Lower Helderberg beds (our Wenlock and Ludlow groups). With these *Pentameri* there occur (in the talus) *Heliolites megastomus* (M'Coy) and *Favosites gothlandicus* (Linn.), abundantly. Petermann Fiord is upon the west coast of Greenland, therefore in all probability these species are derived from higher land to the east in Greenland; the species would seem to indicate that they are from a higher horizon than those collected at Offley Island. Not being, however, found *in situ* we cannot arrive at any just conclusions as to their stratigraphical position. Eighteen species of *Pentameri* occur in the American rocks, and ten in the British Islands; Bohemia has twenty-two. I record one new species from Offley Island, collected by Dr. Coppinger.

Pentamerus Coppingeri, Ether. (Pl. XXV. figs. 2, 3.)

This shell, from Offley Island, I am not able to refer to any known species, either in America or Europe, although it resembles *Pentamerus galeatus* (Dalm.), from our Wenlock series; it is, however, much more elongated than *Pentamerus galeatus*, and has a less incurved umbonal region to the ventral valve. Shell somewhat elongated, longer than wide, sides subparallel.

Ventral valve gibbous, much arched near the umbonal region, about as deep as the dorsal valve, with a shallow mesial fold commencing about the upper half of the valve.

Dorsal valve slightly gibbous; umbo incurved, less so than in *Pentamerus galeatus*; umbonal space wide; the area between the two valves much greater than either in *Pentamerus galeatus* or *P. oblongus*; fissure not seen; lateral margins smooth, anterior margin nearly straight or faintly rounded; surface of both valves nearly smooth or concentrically marked, some specimens more strongly than others.

Our shell differs from *Pentamerus galeatus* in the absence of ribs upon the mesial fold of both valves, and the wavy crenulations upon the lateral portions of the shell, and also in the much wider umbonal space between the two valves. *P. Verneuili*, Hall, from the Lower Helderberg, is a strongly ribbed shell, and the umbo is completely hidden. From *Pentamerus Knightii* our species differs in the want of ribs; but in shape the valves of the two species fairly agree. We have no specimens showing the interior; seven specimens occur.

Loc. Offley Island, lat. 81° 16′. From Upper Silurian, probably Wenlock Limestone.

PENTAMERUS, sp.

This specimen occurs on a block of limestone of considerable size, said by Captain Feilden to have been obtained from a drift boulder in lat. 82° 30′, at an elevation of 40 feet above the sea. This ventral valve I have called *Pentamerus*; it closely resembles *P. conchidium*, Dalm. In drift boulder, lat. 82° 30′.

Genus RHYNCHONELLA, Fischer, 1809.

RHYNCHONELLA NUCULA (Sow.).

Terebratula nucula, Sow. Sil. Syst. t. 5. f. 20.

Only one species of the genus occurs in the collection. It agrees with the above species, so far as I am enabled to determine from one specimen; at all times a troublesome shell, and in every variety, it has the widest distribution, in Britain occurring in almost every locality where the Upper Silurian occurs, from the Llandovery rocks upwards, ceasing only in the Upper Ludlow.

Loc. Bessels Bay, lat. 81° 6′. Upper Silurian.

Genus CHONETES, Fischer, 1837.

CHONETES STRIATELLA (Dalm.).

Orthis striatella, Dalm. Kongl. Svenska Ak. Handl. 1827, p. 111, t. 1. f. 5.

Leptæna lata, Sow. Sil. Syst. p. 610, t. 5. f. 13.

Chonetes striatella, Dav. Monogr. Sil. Brach., Pal. Soc. p. 331, t. 49. f. 23–26.

One individual only; but it is nevertheless enough to declare the presence of this common shell, which in Britain everywhere highly characterizes the Wenlock and Ludlow rocks. The hinge-spines are worn or denuded away (as is generally the case), but the other characters are well preserved.

This is the *Leptæna lata* of Von Buch and of the 'Silurian System' (*loc. cit.*), one of the most abundant shells of the Ludlow group, especially in the upper division. In Scandinavia, Russia, and North America this is also a very abundantly distributed shell.

Loc. Cape Louis Napoleon, lat. 79° 38′.

Genus Atrypa, Dalman, 1827.

Atrypa phoca (Salt.).

Rhynconella phoca, Salt. Sutherland's Journal, vol. ii. p. ccxxvi, t. 5. f. 1–3.

Several specimens of this species occur in the collection. Mr. Salter referred Dr. Sutherland's specimens to the genus *Rhynchonella.* More accurate knowledge of the Brachiopoda has clearly defined those characters that essentially typify the genera. Mr. Salter particularly noticed the resemblance of this shell to Jurassic forms; and it certainly does approach the globose group of the Terebratulidæ in the Oolitic series. The absence of the umbonal foramen and deltidium, however, removes it at once from the *Terebratulæ* or *Rhynchonellæ*, our shell being imperforate. Dr. Sutherland obtained his specimens from Cape Riley, Cornwallis, Leopold, Griffith's, and Seal Islands; Mr. Hart collected his from Bessels Bay (lat. 81° 6′), and Dr. Coppinger obtained it from Bessels Bay and Dobbin Bay (lat. 79° 41′), in much higher latitudes. There can be no doubt about this species being the same as those collected by Dr. Sutherland at the above places.

Atrypa Mansonii (Salt.).

Rhynconella Mansonii, Salt. *loc. cit.* p. ccxxi, t. 5. f. 5.

We have two or three specimens of this species of *Atrypa*; it is a much smaller and flatter species than *A. phoca*, and has the mesial fold more pronounced and sharper. The description by Salter in the appendix to Sutherland's 'Journal' contains all that need be said relative to this species.

Loc. Bessels Bay, 81° 6′.

Atrypa reticularis (Linn.).

Anomia reticularis, Linn. Syst. Nat. ed. 12, vol. i. p. 1152.

Atrypa reticularis, Dav. Mon. Brit. Sil. Brach., Pal. Soc. p. 129, t. 14. f. 1–22.

This shell is found everywhere throughout the Upper Silurian series of the Arctic circle; it is as common there as in the Wenlock series of Britain, Scandinavia, and North America. The forms vary (as with us) according to locality, life, and condition. The variety *aspera* appears to be amongst them; but of this I cannot be sure, the species altogether being so variable. No Palæozoic shell has a wider space or geographical range, or greater range in time. With us it characterizes the Silurian rocks from the Lower Llandovery to the Upper Ludlow, and passes up into the Devonian; and this holds good throughout Europe, wherever the Upper Silurian and Devonian series are represented. It is abundant everywhere in Canada, North America, and the American Arctic rocks, Scandinavia, Russia, Bohemia, and even in Australia, occurring in all stages of the Upper Silurian series, and culminating in the Devonian. Sixty-two species occur of the genus *Atrypa* in the State of New York alone.

Loc. Cape Hilgard, lat. 79° 41′; Dobbin Bay lat., 79° 40′, &c. Upper Silurian.

Genus STROPHOMENA, Rafinesque, 1825.

STROPHOMENA EUGLYPHA (Hisinger).

Leptœna euglypha, Hisinger, Anteckn. t. 6. f. 4.

Strophomena euglypha, Salter, Siluria, t. 20. f. 9; Dav. Monogr. Brit. Sil. Brach., Pal. Soc. p. 288, t. 40. f. 1–5.

This abundant shell in the British Upper Silurian series is now determined to be present in rocks of the same age in the Arctic regions; it has been found both at Cape Hilgard and Cape Louis Napoleon in beds which contain many Wenlock species. There is no doubt of this shell being the above species. We wonder no more specimens have occurred, considering its ubiquity and wide range, being common in the Llandovery, Wenlock, and Ludlow formations of Britain and of the north of Europe.

Loc. Cape Hilgard, lat. 79° 41′, and Cape Louis Napoleon, lat. 79° 38′.

STROPHOMENA SILURIANA, Dav.

Strophomena siluriana, Dav. Monogr. Brit. Silurian Brach., Pal. Soc. p. 303, t. 47. f. 1–4.

I cannot see any difference between our single specimen and Mr. Davidson's figure. Ours is the ventral valve; none of the hinge-area is exposed; and although the horizon of Mr. Davidson's species is somewhat lower or older than that of our form may be, still in a species so variable (especially with age), and having only one specimen, it is not well to be positive either as to stratigraphical position or actual species.

Loc. Cape Leidy, lat. 79° 38′.

Genus MERISTELLA, Hall, 1860.

MERISTELLA TUMIDA (Dalm.).

Atrypa tumida, Dalm. Vet. Akad. Handl. 1828, p. 134, t. 5. f. 3.

Meristella tumida, Dav. Mon. Brit. Sil. Brach., Pal. Soc. p. 109, t. 11. f. 1–13.

A large, but solitary, specimen occurs in the collection. *Meristella* is abundant in the Upper Silurian rocks of both hemispheres, ranging in Britain from the Caradoc to the Wenlock rocks, and occurring in America in the Lower Helderberg, Clinton group, and *Pen-*

tamerus-limestone. *M. tumida* is a Scandinavian as well as a British species; the American form is usually referred to *M. Mariæ*, and occurs in the Niagara group. Our species, "*M. tumida*," is known in Britain, Gothland, Bohemia, and New-York State; we now record it from the Polar area, associated with Wenlock forms.

Genus Strophodonta, Hall*, 1852.

Strophodonta Feildeni, Ether. (Pl. XXV. fig. 4.)

Of this gigantic shell we have only the ventral valve. It is probably the largest species of *Strophodonta* known (if it be *Strophodonta*); it measures 4 inches along the hinge-line by 3 inches in depth. Our single valve may almost be definitely referred to *S. magnifica* of Hall; but owing to its structure being badly preserved its identity may be doubtful; this also prevents my seeing the crenulated hinge-line characteristic of the genus: I name it, however, after Captain Feilden, who so carefully collected the many specimens brought home from the Expedition.

Shell very large, semielliptical, rounded at the extremities of the hinge; hinge-line nearly straight or slightly sloping from the umbo to the two extremities, less than the width of the shell, which is about 4 inches; umbo very small; concentric lines of growth are traceable; also longitudinal impressions or remains of slender ribs passing from the umbo to the ventral margin, but not so pronounced as in the genus *Streptorhynchus*. I know of no shell in the European Palæozoic rocks at all resembling this species. The genus is well represented in the Lower Helderberg and Oriskany series of New York, no less than thirty-four species being known to the State geologist. Our specimen might almost be regarded as a gigantic *Orthis* or *Chonetes*. I, however, prefer referring it to *Strophondonta*.

Hall's species, *S. magnifica*, occurs in the Oriskany Sandstones (Lower Devonian) of New York and Maryland; other species occur in the Hamilton group, Iowa.

Loc. Cape Hilgard, lat. 79° 41′. Upper Silurian.

Class LAMELLIBRANCHIATA.

Not a single species of this class has occurred in the Silurian or Carboniferous series under examination; and, singular as it may appear, no bivalve shell has been collected, so far as I can ascertain, by any previous Arctic expedition either from rocks of the Silurian, Devonian, or Carboniferous series: yet it cannot be supposed that no forms of

* A group of Strophomenoid shells possessing a crenulated hinge-line and no foramen in the ventral valve; the valves closely interlock, and the two valves closely follow each other.

Pelecypod Mollusca lived within the Arctic circle during the long ages of Palæozoic time. Five genera and 150 species of Silurian *Monomyaria* are known in the North-American area, and 27 genera and about 230 species of *Dimyarian* forms, yet none have been collected north of lat. 60°. Only three species have been found in Newfoundland—two in the Calciferous group and one in the Chazy series, and in the Levis formation only two. Adding this to the few Gasteropoda found, it almost appears that littoral conditions scarcely existed through these eras over a very large area north of lat. 70°, a circumstance somewhat confirmed by the rich Coral fauna, Polyzoa, Heteropoda, Brachiopoda, and Cephalopoda (deep or open sea or pelagic forms) occurring so persistently in all the collections made. We could scarcely have failed to recognize the presence even of portions of the shells of this division of the subkingdom Mollusca proper had they occurred. As above stated, none have been found either in the Silurian or Carboniferous series in high latitudes. This cannot in any way be due to temperature, as the fossil fauna now represented as far north as 82° 43′ could not have existed at low temperatures. Probably along the coast it was fiord-like, with the water deep; and littoral conditions may not have existed to any extent, there being no true beaches. The Coral fauna living in the deeper portions of the sea were associated with the Brachiopoda and Polyzoa. The Cephalopoda and Heteropoda being pelagic would readily account for their presence with the other classes mentioned. In no other way can we account for the absence of the Lamellibranchs. We have now existing in the highest latitude an abundant and characteristic Lamellibranchiate fauna, which occurs also in Post-Tertiary beds as high as latitude 82° 30′, at Shift-Rudder Bay, where in the "grey mud deposits," up to an altitude of 200 feet, *Astarte borealis, Mya truncata, Saxciava rugosa, Cardium islandicum, Leda arctica, L. pernula,* and *Pecten grœnlandicus* abounded. At Lincoln Bay, Grinnell Land, lat. 82° 8′, the same species occur 50 feet above sea-level, the shells covering an area of many miles. At Dumb-bell Harbour, lat. 82° 30′, and 400 feet above sea-level, Feilden found the same Mollusca and calcareous "rods of *Funicularia quadrangularis*" abundantly distributed. This species, according to Mr. Norman, occurs at Oban, and was dredged by the 'Porcupine' in the Minch (1869); it is also found in the Kattegat, in the Scandinavian seas. Again, on the plateaux at Floeberg Beach, lat. 82° 27′, and at an elevation of 800 feet, the valves of *Mya truncata* occur; even up to an elevation of 1000 feet, at Watercourse Bay, lat. 81° 44′, these mud beds with scratched erratics and *Mya truncata, Saxciava rugosa, Astarte borealis,* and *Pecten grœnlandicus* were met with. Thus through the presence of these Mollusca we obtain clear evidence of the continuous elevation of the Polar land (1000 feet) since the close of the Miocene epoch, or that age when our modern Arctic and boreal fauna became established. The causes influencing the paucity of species, as compared with individual abundance, can only be accounted for by a knowledge of the physical conditions under which life was and is sustained within the Polar area; that they must have been very different, so far as the Lamellibranchiata are concerned, during the deposition of the Carboniferous and Silurian rocks appears evident, for we find none.

Class GASTEROPODA.

Very few species of this class have been collected, and with one or two exceptions all are small species—not that they are dwarfed forms through low temperature or paucity of food or other causes; the whole group seems to be poorly represented, so far as the collections made are any test. Large species of the genus *Murchisonia*, one or two *Loxonemæ*, and species of *Macrocheilus* and *Holopella*, *Rhaphistoma* or *Euomphalus*, *Acroculia*, and *Platyceras* seem to be all that occur in the collection. Amongst the Carboniferous-limestone series not a species occurs. It is seldom that Gasteropoda and Brachiopoda are associated together, and in the Carboniferous series they are mostly of the latter class; hence, perhaps, the horizons collected from were not favourable to the Gasteropoda during their deposition. I can hardly imagine a great paucity of species in this class in these Upper Silurian rocks, considering that the bathymetrical conditions must have been favourable to their life, development, and distribution.

Considering the fauna of the Silurian rocks of North America and Canada, as well as that of our own country, from rocks of the same age, associated as they are with a similar assemblage of Cœlenterata, Crustacea, and Brachiopoda, we should expect to find more species. Doubtless the difficulty in collecting was great, horizontal extension, or *space*, and vertical distribution, or *time*, being two elements in the collecting not easily realized under the adverse climatal circumstances and other difficulties attending such an expedition; for it could only have been from the faces of the cliffs where the beds were exposed that fossils could be obtained *in situ*. As regards Post-Tertiary species, very few of this class occur in the living molluscan fauna of the Polar area, *Trochus umbilicatus*, *T. olivaceus*, and *Cylichna striata* being amongst the chief species. The last-named delicate shell (*Cylichna striata*) occurs in a fossil state at Spitzbergen and in the Clyde beds, as well as in the State of Maine. *Trichotropis borealis*, *Pleurotoma Trevelyana*, *Trophon clathratum*, and *Buccinum tenue* are the chief forms of Gasteropoda in the Post-Tertiary deposits; but none came home in the Carboniferous collection.

Genus Murchisonia, D'Archiac and DeVerneuil, 1841.

Murchisonia latifasciata, Ether. (Pl. XXVII. fig. 1.)

Fortunately we have a small portion of the shell on this single specimen which shows enough structure to enable me to say that I know no shell like it, or rather cannot find either description or figure that agrees with it. These shells, which resemble elongated *Pleurotomariæ*, are at all times difficult to determine: in the present case we have only two whorls, the body-whorl and that adjoining;

the aperture is not seen, neither is the columella, or the outer lip, complete, so that I have to base my determination upon the body-whorl.

The fascia, or band, is a quarter of an inch wide, having gently curved concave lines of growth or deposit, *i. e.* concave or thrown backwards with relation to the lip; the upper and lower areas of the body-whorl (above and below the fascia) are marked by delicate lines of growth in reverse position, and lying at an angle of 30°, that above the fascia being to the right, that below to the left; the shell must have been 5 or 6 inches in length. Billings, in the "Geology of Canada" (Geol. Survey of Canada, vol. i. Palæozoic Fossils, p. 234), figures from the Chazy series a shell he calls *M. Augustina*, which quite equals in size the above species, but wants the broad fascia.

Loc. Offley Island, 81° 16′. Dr. Coppinger's collection.

MURCHISONIA, ? sp. (Pl. XXVII. fig. 2.)

Whether this is a *Macrocheilus* or a *Murchisonia* I am at a loss to know: the shell measures 4½ inches in length, and must have had seven or eight whorls; four interior moulds of the lower whorls are left to us, *but no outer shell* remains to aid in the determination or description of the species. Many large Canadian and North-American forms have been described and figured by Billings and Hall &c. from rocks about the same horizon; it is not, however, safe to refer our single specimen to them: it does not possess any fascia or band round the whorls, a character peculiar to *Murchisonia*; but we have no true shell remaining.

Loc. Offley Island, lat. 81° 16′. In white limestone, collected by Dr. Coppinger.

Genus RHAPHISTOMA, Hall, 1847.

RHAPHISTOMA ÆQUALE (?), Salter.

Raphistoma æquale (?), Salter, Murchison's Siluria, ed. 4, p. 197, foss. 40. f. 2.

Helicites qualteriatus, Schloth.

Platyschisma, Euomphalus, Scalites, Rhaphistoma, Helicotoma, and flattened forms of *Pleurotomaria* so resemble each other when crushed or in the form of casts, that it is no easy matter to distinguish them, all appearing much the same when masked by the matrix in which they occur. Although we have only one specimen from Cape Hilgard, there can be no doubt about the genus. *R. æquale*, Salter (*Helicites Gualteriatus*, Schl.), seems to be our shell. It is associated with *Maclurea magna, Halysites catenulatus, Favosites gothlandicus*, and *Favistella*. I refer it to *R. æquale*, which it more nearly resembles than any American form I am able to find. The upper surface of some of the acuminate forms of *Maclurea*, which have the margin of the whorl extremely acute, would pass for this shell; but the last whorl when exposed is not so deep as in *Maclurea*, it is flatter and more acute and discoid also. Again, the subtrigonal mouth and closely fitting sutures between the whorls distinguish *Rhaphistoma* from *Maclurea*.

Loc. Hayes Point, lat. 79° 42′.

Genus Helicotoma, Salter, 1856.

Helicotoma Naresii, Ether. (Pl. XXVII. fig. 3.)

This very discoidal shell is the only representative of what I believe to be the genus *Helicotoma*. Hall has described (Pal. N. Y. vol. i. p. 9, t. 3) a shell he terms *Euomphalus uniangulatus*, which, in some respects, resembles our species, but certainly is not the same.

Sp. char. Shell discoidal, depressed, almost flat, composed of five or six whorls gradually increasing in size, the inner edge of each whorl bevelled on the concave or umbilical side at an angle of 15°; surface of the shell strongly marked by transverse lines of growth, which arch forward on the sides of the whorls, but are reflected backwards along or near the sutural junctions; umbilicus open, all the whorls exposed; a spiral band appears to run along the middle of the whorl; the aperture not seen, owing to compression; the spire must have been greatly depressed, probably level with the surface of the shell.

The genera *Euomphalus* and *Ophileta* might well receive our shell; yet I prefer referring it to *Helicotoma*; but its preservation is such as to preclude strict determination. Billings figures a shell which he calls *Ophileta? bella* (Geol. Canada, Pal. Foss. p. 30, f. 301), which very closely resembles our form; he refers this to Hall's *Euomphalus* (*Helicotoma*) (*Ophileta*) *uniangulatus*, but comments upon the flatness and more moderate concavity of the umbilicus. *Maclurea crenulata* and *M. speciosa*, Bill., simulate our species, showing how closely allied are these Euomphaloid forms. As before stated, we cannot compare either the entire aperture of *Maclurea*, or ventral sinus and notch in *Ophileta*, on account of the state of preservation; and our remarks are confined to a single specimen. Both Billings's and Hall's shells occur in the upper part of the Quebec group; about fifteen species are known on the American continent*.

Loc. Offley Island, lat. 81° 16′. Associated with *Pentamerus Coppingeri*, *Favosites gothlandicus*, *Macrocheili*, and large *Cyrtocerata*.

Genus Holopella, M'Coy, 1855.

This genus occurs here and there on some of the shelly slabs of Silurian Limestone taken from the cliff-talus and drift at Hayes

* Meek, in his Report on the Geological Survey of Ohio, vol. i. pt. 2 (Palæontology), p. 220, t. 19. f. 3, t. 20. f. 1, describes and figures a species of *Euomphalus* (*E. De Cewi*, Billings) which much resembles our shell. Billings obtained his from the Corniferous group (Devonian), Co. Haldinand, Canada West; Meek from Kelley's Island, Lake Erie. Billings described this species in the 'Canadian Journal' (July 1861), p. 358; Dev. Foss. Canada West, p. 94, f. 131, 132, woodcuts. It is the *Euomphalus Conradi*, Hall, Report, 1861, p. 107.

Point, lat. 79° 42′, and Cape John Barrow. They resemble forms common in the Ludlow, Wenlock, and Upper Silurians generally of Britain, especially *H. gregaria*; no characters occur to distinguish them; but the entire peristome and numerous gradually increasing smooth whorls leave no doubt as to the genus. None are sufficiently well preserved to enable me to describe them; their stratigraphical value is also lost owing to their being drifted specimens. *Orthoceras*, *Strophomena*, *Rhynchonella*, and *Macrocheilus* occur on the slabs.

Loc. Hayes Point, lat. 79° 42′, and Cape John Barrow, lat. 79° 48′.

Genus Acroculia, Phillips, 1841.

Acroculia haliotis (Sow).

Nerita haliotis, Sow. Sil. Syst. t. 12. f. 16; Murchison, Siluria, t. 24. f. 9.

Many examples of this shell are in the collection, and, as usual, as many varieties; for no two are alike. *A. prototypa*, Phill., may in some cases be referred to *A. haliotis* (Sow.); but, as a rule, it is naticoid rather than neritoid in form. Capt. Feilden's specimens are in excellent preservation; and although so much variation is known to occur in the species of this group, yet I am disposed to refer some specimens to a new species to be next described. *A. haliotis* occurs at Bessels Bay and Dobbin Bay (lat. 79° 40′), and is widely distributed, ranging from Bohemia and Thuringia to Britain and Ireland; and I believe the specimens collected by Dr. Coppinger are the same species. No less than eighty species are known in the Silurian rocks of the two hemispheres, recorded under the names *Capreolus*, *Platyceras*, *Pileopsis*, and *Acroculia*. Forty species are American and twelve German; the remainder are distributed generally through the European Silurians.

Genus Platyceras, Conrad, 1840.

Platyceras naticoides, Eth. (Pl. XXVII. figs. 4, 4*a*.)

I cannot find any species of *Platyceras* or *Acroculia* answering to this, which I term *P. naticoides* from its extreme resemblance to many species of that genus as well as many forms of *Platyostoma*; but, strong as is the general resemblance, still the apex of the spire, indented suture, and abnormal body-whorl remove it from *Acroculia*. The extensive genus *Platyceras* of Conrad receives forms so varied and abnormal that almost any Palæozoic naticoid shell may be placed within its limits. Forty species are recognized by Hall as coming chiefly from the Helderberg group of America. Our Upper Silurian *Platyceras* has not occurred above the Silurian rocks of the west. The genus *Strophostylus* of Hall may receive these thin shells with expanded volutions (especially the last or ventricose body-whorl) and small spires; but I prefer referring them to *Platyceras*.

Sp. char. Shell subglobose, somewhat elongate in the direction of the spire, or obliquely conical; spire small, loosely or irregularly coiled; volutions few, rounded, usually four, contiguous, the sutures varying in individuals; body-whorl large; peristome expanded and entire, slightly sinuous; surface of shell finely striated, near the peristome rather coarsely so, or lamellose and reflected backwards; columella not seen in any of the specimens; the peristome appears entire.

Our species would belong to that division of *Platyceras* having the whorls contiguous, not free.

Hall's genus *Platyostoma* contains shells resembling these acroculiiform and *Pileopsis*-like species. Dr. Coppinger collected these at Bessels Bay.

Loc. Bessels Bay, lat. 81° 6′.

HETEROPODA (NUCLEOBRANCHIATA).

This order of Pelagic Mollusca is represented by two genera of the family Atlantidæ (*Bellerophon* and *Maclurea*); both are widely distributed. The former genus is known to contain about 140 species, ranging from and through the lowest Silurian rocks up to the Carboniferous Limestone. Our two specimens of *Bellerophon* are from the Upper Silurian of Bessels Bay. Seventy species occur in the Palæozoic rocks of North America and Canada alone, 150 in Britain and Europe.

The Atlantidæ are all provided with a well-developed shell, which in the older genera was inflated or discoidal and symmetrical; in *Maclurea* the aperture of the shell was closed by an operculum. Both *Bellerophon* and *Maclurea* occur in the series of fossils brought home by Captain Feilden—*Bellerophon* from Bessels Bay and *Maclurea* from Cape Frazer, Cape Hilgard, and Cape Louis Napoleon. *Maclurea* is associated with *Receptaculites* in each locality, as well as with the large specimens of *Halysites* referred to in this commentary. I can only determine one species of *Bellerophon* amongst the 'Discovery' collection made by Dr. Coppinger, the forms occurring being, I think, the same—neither of them in good condition. I notice them, but leave specific determination.

These two heavy-shelled Nucleobranchs predominated in the Silurian seas of America, Grinnell Land, and probably Greenland—*Bellerophon* being the Bessels-Bay genus, *Maclurea* characterizing the beds at Cape Louis Napoleon, Cape Hilgard, and Cape Victoria.

Genus Maclurea, Lesueur, 1818.

Lesueur's genus is numerically well represented in the collection, and probably by two if not three species.

In the British Islands we know this shell only from the Lower Silurian rocks, not ranging higher than the Caradoc (*M. macromphala*, M'Coy), the Arenig and Llandeilo series being its chief horizon. At Durness, the most northerly part of Sutherlandshire, N.W. Highlands, *M. Peachii* occurs abundantly in beds that are equivalent to the Arenig or lowest Llandeilo series at Quebec. *M. Logani*, Salter, occurs also in the calcareous schists of the same series at Aldeans, Ayrshire, with *M. magna*; and the small *M. macromphala* ranges into the Caradoc rocks at Craig Head near Girvan. It is interesting to find *M. magna*, which is abundant in the United States, occurring in the Aldeans Limestone rocks of the same age in Scotland. We do not know this genus in England or Wales; yet no less than twenty-two species occur in North America, and ten in North Britain and Europe. The Aldeans Limestone and Arenig rocks of Durness in North Scotland contain five species, through three of which we are allied to North America and Canada, viz. *M. magna*, Lesueur, *M. Logani*, Salter, and *M. matutina*, Hall.

Maclurea magna, Lesueur.

Maclurea magna, Lesueur, Journ. Acad. Nat. Sci. Philad. vol. i. p. 312, t. 13. f. 1–3; Hall, Pal. N. Y. vol. i. p. 26, t. 5, 6; M'Coy, Brit. Pal. Foss. p. 300, t. 1–4. f. 13.

Several specimens of this large species occur in the collection made by Captain Feilden at Cape Louis Napoleon, Cape Hilgard, Cape Frazer, and Victoria Head. Those brought home quite equal in size Hall's figures in the 'Pal. New York,' vol. i. t. 5. f. 8, which occur in the Chazy Limestone or "Canadian" division of the Lower Silurian of North America (United States). This shell ranges from the N.E. of York State to Kentucky and Tennessee, and N.W. to Lake Superior (lat. 48°). Now we have it from lat. 80°, or 32° further north. Doubtless wherever this division of the Lower Silurian rocks appears, from New York to Cape Louis Napoleon, this characteristic shell will be found.

Mr. Salter was inclined to consider *M. magna* and *M. Logani* to be the same species. *M. magna* was first found in Britain at Knockdolian Quarry and at Aldeans (Ayrshire); its great interest then as now, in this country, as in America, consists in its limited geological range, being, in America, confined to the Chazy Limestone (our Arenig group). We have no means of knowing its geographical range here, as the Scotch rocks containing *M. magna* strike out to sea under the Atlantic in Ayrshire. The Inch-na-Danff and Durness Limestones near Cape Wrath, containing the same genus, are a mere remnant of a once widely extended group of rocks, and undoubtedly the same as the Quebec group, so rich in Graptolites.

Mr. Billings names and describes (but does not figure) a species he terms *M. ponderosa*, closely allied to *M. magna* from the Levis formation above the Chazy; but it evidently is not the same shell. We possess *M. magna* from the Aldeans Limestone of Scotland, and *M. Peachii* from the Durness beds—rocks probably of Arenig age, or ranging from that to Caradoc. This wide geographical range of *M. magna* is important, and tends to show the relation of the Scotch Silurian fauna to that of North America, just as the Carboniferous series of Newfoundland may also be correlated with those of Scotland.

Loc. Cape Louis Napoleon, lat. 79° 38′; Cape Hilgard, lat. 79° 41′; and Victoria Head, lat. 79° 12′.

Maclurea Logani, Salter.

Maclurea Logani, Salter, Report Brit. Assoc. 1851, Trans. Sect. p. 63; Quart. Journ. Geol. Soc. vol. vii. p. 166, t. 8. f. 7; Geol. Surv. Canada (Canadian Organic Remains), decade 1, p. 1, t. 1.

This shell is decidedly distinct from *M. magna*, although in many respects closely allied. It agrees with our British species in every particular. It is well figured and described by Salter in the Memoirs of the Geol. Survey of Canada, Figures and Description of Organic Remains, decade 1, pp. 1–10, t. 1. f. 1–6. *M. Peachii*, Salter, from the Durness and Inch-na-Danff Arenig rocks, may be taken for this shell. *M. Logani* becomes nearly as large as *M. magna*; but differences exist which cannot be discussed in a general notice. No opercula have appeared in the series collected. *M. Logani* often measures 3½ inches across or in width, and differs from other species by its extreme flatness on the lower or umbilical side, and few whorls, as well as great depth of the whorl, which often exceeds the width.

Mr. Hart and Dr. Coppinger collected this species at Bessels Bay, lat. 81° 6′.

Genus Bellerophon, Montfort, 1808.

Bellerophon, sp.

We have two specimens, probably of two species, of this genus, but neither of them complete; and whether the mouth-aperture was much expanded cannot be determined. The median keel was evidently well developed, and strong lines of growth pass off nearly at right angles to the keel and are reflected backwards towards the umbilicus.

Our specimens may both be inner portions of the shell, or the first portions of the spiral coils. We can therefore do little more than record the occurrence of *Bellerophon*. The American Silurian rocks contain thirty species of this genus, and the European sixty species, seven of which are common to the two hemispheres.

Loc. Bessels Bay, lat. 81° 6′.

Class CEPHALOPODA.

Few Cephalopoda have been collected, four species of *Orthoceras* and one *Cyrtoceras* being all brought home. The distribution of the order Tetrabranchiata in time is a problem of great interest. The seas of the globe during every epoch from the Silurian to the present day have held this Order. It is the oldest of the two, and attained its maximum in the Palæozoic periods, being now represented only by one species (*Nautilus pompilius*), confined to the warm seas of the equatorial regions. The true Nautilidæ and Orthoceratidæ are essentially Palæozoic. The latter, through two genera (*Orthoceras* and *Cyrtoceras*), survived or lived on to Mesozoic times, dying out in the Triassic seas. No Dibranchiate Cephalopod has yet occurred or been found in any group of Palæozoic rocks; but the oldest of the two sections in this order (the Decapoda) contains the extinct family Belemnitidæ, commencing in the Trias and ranging up to the close of the Cretaceous period. Few if any Octopoda are known fossil.

The Silurian rocks of Bohemia, the British islands, Scandinavia, and America have yielded nearly 2000 species of Tetrabranchiata, America alone 450. We must probably, therefore, look to the American continent for the source of the Cephalopod fauna of the Palæozoic rocks constituting the shores of the Arctic seas. Hitherto only eight species have occurred in Arctic America, viz. one *Cyrtoceras*, one *Lituites*, five *Orthocerata*, and one *Actinoceras*. I am now able to add three more species to the list of Arctic Tetrabranchs—two *Orthocerata* and one *Cyrtoceras*. There are other fragments which probably would illustrate more had the materials been better.

Bohemia exceeds all areas in having yielded to the researches of Barrande no fewer than 830 species of Silurian Tetrabranchiate Cephalopoda.

Genus Orthoceras, Breynius, 1732.

Orthoceras imbricatum, Wahlenberg.

Orthoceratites imbricatus, Wahlenb. Nova Acta Upsal. 1827, p. 89.

Orthoceras imbricatum, Hall, Pal. N. Y. vol. ii. p. 291, t. 61, 62; Siluria, t. 29. f. 7.

A vertically divided half or completely crushed specimen of an *Orthoceras* from Cape Louis Napoleon I refer to *Orthoceras imbricatum*. It occurs in the Niagara group of North America, and in the Ludlow series of Wales. Our specimen measures 4 inches in length; but the diameter appears increased, owing to flattening. Nothing can be determined as to the position or nature of the siphuncle, owing to the crushed state of the shell.

Loc. Cape Louis Napoleon, lat. 79° 38′; east of Dobbin Bay, Grinnell Land.

Another specimen (marked D 12′), from the Upper Silurian of Dobbin Bay, I take to be the same species. This shows the internal portion, where the concave septa correspond in distance to those in the weathered outer portion of the vertical half above described. Four other portions from Offley Island I also refer to *O. imbricatum*; they are considerably smaller, but in every other particular are the same.

Loc. Offley Island, lat. 81° 16′, in white limestone. Cape Louis Napoleon, lat. 79° 38′. Upper Silurian.

ORTHOCERAS NUMMULARIUM, Sow.

Orthoceras nummularius, Sow. Sil. Syst. p. 632, t. 13. f. 24; Siluria, t. 26. f. 5.

O. cochleatum, Schloth.

O. crassiventris, Wahlenb., His. Leth. p. 30, t. 10. f. 3.

Sowerby's figure in the Silurian System, t. 13. f. 24, and the repeated figure in Siluria, t. 26. f. 5, in every particular resembles our single specimen collected by Dr. Coppinger from the Upper Silurian series of Bessels Bay. It appears to be the *O. cochleatum* of Schlotheim, and probably the *O. crassiventris* of Wahl. (His. Leth. p. 30, t. 10. f. 3). Although Schlotheim has priority as to date, I still retain Sowerby's name. The figure is good, and agrees with our fragment, which shows 6 siphuncular chambers. The want of radiating plates determines this not to be an *Actinoceras*, nor can I detect any inner or central inflated tube within the chambers as in that genus; and the siphuncular beads having no constriction removes it from *Huronia*. I draw attention to these differences from the unsatisfactory state of the fragment under description. Both by description and figure it is Sowerby's *O. nummularium*.

Loc. Bessels Bay, lat. 81° 6′.

Genus CYRTOCERAS, Goldfuss, 1832.

CYRTOCERAS, sp.

Only fragments of what must have been a large species have been brought by Dr. Coppinger from Offley Island. It appears to be a portion from near the centre of the curved shell, measuring 9 inches, and the diameter 4 inches; the siphuncle is subspherical.

This species must have been of considerable size; the chambers are as closely arranged as those of *O. imbricatum*; and, but for the curvature, it might be mistaken for that form. Sixty species occur in the American Silurian rocks, and 293 in Europe; of these latter, 254 are Bohemian and 20 Russian. Next to *Orthoceras*, which contains 704 species, this genus possesses the greatest number. As before stated, Arctic America has yielded 8 species of Cephalopoda—*Lituites*, *Actinoceras*, and *Cyrtoceras* 1 species each, and *Orthoceras* 5. Bohemia, on the other hand, heads all areas in having yielded to the researches of Barrande no less than 830 forms.

Loc. Offley Island, lat. 81° 16′.

CARBONIFEROUS.

The only series of Carboniferous-limestone fossils obtained during the Exploration were collected at Feilden Isthmus, lat. 82° 43′, the highest latitude attained; consequently the Carboniferous series are the nearest known fossiliferous rock to the Pole; they are underlain by a patch of Devonian, which appears to be faulted against the Cape-Rawson beds, which occupy so large an area on Grinnell Land, and underlie the whole of the fossiliferous rocks north of latitude 78° or

80°. The strike of these Carboniferous Limestones is towards Spitzbergen and Franz-Joseph Land, whence a rich fauna of this age is known and described by Toula.

Rocks of this age were not determined eastwards of Robeson Channel or on the extreme northern shores of Greenland as far as Cape May. Neither did Lieut. Aldrich obtain any evidence of such (according to the rocks brought home) during his memorable sledge journey to the westward and round Cape Columbia to Cape Alfred Ernest. Looking at the collection obtained from Feilden Isthmus, composed chiefly of Brachiopoda and Polyzoa, and the mode of their occurrence, I should be disposed to regard it as a highly typical one, and as indicating the presence of Carboniferous strata, which upon careful research and examination would yield a large fauna. The present collection was obtained under great difficulties, and is therefore by no means numerically representative*. Four species of Actinozoa, four or five genera and twelve species of Polyzoa, and five genera and twelve species of Brachiopoda occur in the collection; but there were no Lamellibranchiata in either the Carboniferous or the Silurian series brought home.

Class ACTINOZOA.

Group TABULATA.

Genus SYRINGOPORA, Goldfuss, 1826.

SYRINGOPORA, sp.

This universally distributed genus of corals in the Carboniferous rocks of Europe and America is only represented in the Polar collection by two specimens.

The Halysitinæ are a variable family, and unless the species are well preserved they are better left undetermined. *Syringopora* is ubiquitous, the abundant forms in Britain being *S. ramulosa*, *S. reticulata*, and *S. geniculata*. Keyserling, Bronn, and D'Orbigny have described this genus under the name of *Harmodites*. Twelve species are known in the Devonian rocks of North America and Canada, three in the Carboniferous of North America, and twelve in Europe, *S. reticulata* being the species common to the two continents; eight species occur in the Carboniferous rocks of Russia (four of these in the Ural chain), five in Belgium, and three in France, *S. ramulosa*, *S. reticulata*, and *S. geniculata* being common to all European areas.

Loc. Feilden Isthmus, lat. 82° 43′.

* It is much to be regretted that by far the greater portion of the Carboniferous collection made by Captain Feilden at Joseph-Henry Peninsula during the sledge journey was left behind, owing to the inability of the crew to drag the increased weight on the sledge. Considerably more than one half were abandoned; only the few secured and brought away by the energetic persistency of the weakened explorers, and noticed in this communication, were saved.

Genus Chætetes.

(*Monticulipora*, D'Orb. 1850.)

Chætetes, sp. allied to C. tumidus (Phillips).

Calamopora tumida, Phill. Geol. Yorksh. vol. ii. p. 200, t. 1. f. 49–57.

Favosites tumida, Portlock, Londonderry, p. 326, t. 22. f. 4.

Monticulipora tumida, De Kon. Nouv. Rech. sur les Anim. Foss. Terr. Carb. Belg. p. 143, t. 14. f. 3.

Eight or ten portions of this branching species are in the collection; they much resemble *Chætetes* (*Monticulipora*?) *inflatus*, De Koninck, from the Carboniferous Limestone of Visé (Belgium); they are also equally near *C. fruticosus*, Hall, from the Hamilton group of North America. This is evidently a very variable species, differing to almost any extent in size and habit.

Sp. char. Corallum branching, the branches round or subcylindrical or subdepressed; corallites prismatically arranged; calicular openings nearly at right angles to the axis or very oblique to the exterior surface, or in their upward growth they are nearly vertical, until bent or inclined to the face of the corallum, where they (the calices) become nearly horizontal. The ramose and branching habit of this species of *Chætetes* (*Monticulipora*) is clearly shown in the fragments collected, and, judging from their diameters, it must have been of considerable size.

The Chætetinæ, as a group, have received many dissimilar and doubtful genera. The restricted genus *Chætetes* alone absorbs ten genera; the species *C. tumidus* has about forty synonyms, and *C. inflatus* ten. I refer the specimens collected by Captain Feilden to *C. tumidus*, as being its nearest ally.

Hab. Feilden Isthmus, lat. 82° 43′.

Group Rugosa.

Genus Lithostrotion, Fleming, 1828.

Lithostrotion junceum (Fleming).

Caryophyllea juncea, Flem. Brit. Animals, p. 509.

Siphonodendron sexdecimale, M'Coy, Brit. Pal. Foss. p. 109.

Lithodendron sexdecimale, Phill. Geol. York, vol. ii. p. 202, t. 2. f. 11–13.

The genus *Lithostrotion*, through three species, connects, with other genera, the Carboniferous Cœlenterate faunas of America and Europe. No less than twenty-eight species are European and five American, three of which are common to both continents, viz. *L. basaltiforme*, *L. cæspitosum*, and *L. floriforme*. From our single specimen, *L. junceum* is now recorded for the first time from the western hemisphere, and at the most northerly land known (lat. 82° 43′). The corallites are too small for its allied species, *L.*

irregulare; no transverse or connecting tubes, as in *Syringopora*, can be made out: this and traces of the columella, two essential characters, remove it from *Syringopora*. The diameter of the corallites differs, as in the British species. M'Coy's genus *Siphonodendron* is clearly a modification of Fleming's older genus *Lithostrotion*, although M'Coy dwells upon the mode of development or increase by lateral budding in *Siphonodendron*, as distinguished from lateral division of the old calice and dichotomous fissure of the stem, also on the simple axis and conoidal transverse diaphragm in *Siphonodendron*, the axis in *Lithostrotion* being large and cellular and there being no diaphragm.

Captain Feilden collected this one specimen at Feilden Isthmus, lat. 82° 43′, in a grey limestone.

Class ANNELIDA.

Genus Serpulites, MacLeay, 1839.

Serpulites carbonarius, M'Coy, Carb. Foss. Ireland, p. 170, t. 23. f. 32 (or allied to this species).

The order Tubicola is represented in the collection only by this one species; it is badly preserved, but there is enough to show that it may be the *Serpulites carbonarius* of M'Coy, *loc. cit.* It was collected at Rawling Bay.

Subkingdom MOLLUSCOIDA.

Class POLYZOA (BRYOZOA).

The Polyzoa collected by Captain Feilden are both numerous and important and demand careful notice, especially as they are from rocks of the highest latitude in which fossils have yet been obtained, viz. Feilden Peninsula, between lat. 82° 43′ and 82° 50′ N. The specimens, too, are finely preserved, and capable of comparison with known Carboniferous-limestone species from America, Spitzbergen, and Europe.

I append, through the aid of Mr. R. Etheridge, Jun., a valuable bibliography and description of the species collected, so far as their preservation will allow. All the specimens are Carboniferous, and therefore the group needs no reference under the Silurian portion of this paper. It is singular that we have no Silurian forms of Polyzoa in the collection, considering that, bathymetrically, we should expect to find them associated with the numerous corals and Brachiopoda.

The bibliography and descriptions will greatly aid in the study of the characters of the Carboniferous Polyzoa of the northern hemisphere, especially as so much has been done by the American naturalists, notably by Hall, Meek, and Worthen, and by Geinitz, Dr. Nicholson, and others who have investigated the Polyzoa on that continent.

It may not be out of place, in the first instance, to notice what is already known in relation to the subject of Arctic Palæozoic Polyzoa. With this end in view I have drawn up the following bibliography, and regret not being able to offer a more extended account.

1828. In the "Topographical and Geological Notices" forming Appendix I. to Franklin's 'Narrative of a Second Expedition to the Polar Seas in the years 1825–27 &c.' *, Dr. J. Richardson describes the limestone of Lake Winnipeg, and mentions its fossil contents, amongst which are Corallines †. The Winnipeg limestone, with that of the Elk and Slave Rivers, is considered by Dr. Richardson to be Carboniferous.

1830. An article on Arctic geology was given by Prof. Jameson in the 'Edinburgh Cabinet Library' ‡, in which were described specimens from Cape Fanshawe, in that part of Spitzbergen called New Friesland by the officers of Captain Parry's Expedition. The specimens in question consisted of Madrepores, Retepores, *Orthoceratites*, *Terebratulites*, and *Cardites* §.

1839. The geology contained in the Zoology of Captain Beechey's 'Voyage &c. to the Pacific and Behrings Straits performed in His Majesty's Ship 'Blossom' &c.' ‖ was contributed by Prof. Buckland. A limestone was found at Cape Thomson, on the north-west coast of North America (lat. 67° 6′ N., long. 165° 45′ W.), "abounding with organic remains similar to those of the limestone of Derbyshire" ¶. Amongst the specimens collected are mentioned "the *Producta Martinæ* and other *Productæ* . . . . . . and other specimens of *Flustræ*" **.

1846. Count von Keyserling gave descriptions of a number of Polyzoa from the Palæozoic rocks of the remote and arctic region of Petschora Land, in N.E. Russia ††. The forms there described are:—

Ceriopora bigemmis ‡‡, *Keys.*, p. 184; atlas, t. 3. f. 13.
Fenestella antiqua, *Goldf.*, p. 186; atlas, t. 3. f. 9, *a* & *b*.
 „ carinata, *M'Coy*, p. 186; atlas, t. 3. f. 12, *a* & *b*.

* Page i.
† Page lv.
‡ 'Narrative of Discovery and Adventures in the Polar Seas and Regions, &c.,' by Profs. Jameson, Leslie, and Hugh Murray. Edinburgh, 8vo, 1830, p. 399.
§ Page 402.
‖ London, 4to, 1839, p. 157.
¶ *Loc. cit.* p. 171.
** *Ibid.* p. 172.
†† Geognostische Beobachtungen, wissenschaftliche Beobachtungen an seiner Reise in das Petschora-Land im Jahre 1843, 4to, 1846: atlas, folio.
‡‡ This is probably a *Rhombopora*, Meek.

Ptylopora pluma, *M'Coy*, p. 187 ; atlas, t. 3. f. 11.
Polypora orbicribrata, *Keys.*, p. 189 ; atlas, t. 3. f. 7.
„ bifurcata, *Fisch.*, p. 189 ; atlas, t. 3. f. 8, *a* & *b*.
„ infundibuliformis, *Goldf.*, p. 190.
„ biarmica, *Keys.*, p. 191 ; atlas, t. 3. f. 10.
Coscinium cyclops, *Keys.*, p. 192 ; atlas, t. 3. f. 5, *a* & *b*.
„ stenops, *Keys.*, p. 193 ; atlas, t. 3. f. 6, *a–c*.

In the same year Prof. de Koninck published a paper, "Notice sur quelques Fossiles du Spitzberg" *, in which he mentioned a *Fenestella* resembling *F. anceps*, Schl., in the size of its fenestrules. The fossils from Bell Sound were thought by Prof. de Koninck to be of Permian age.

1847. A translation of a memoir by Baron von Buch, "Ueber *Spirifer Keilhavii*, über dessen Fundort und Verhältniss zu ähnlichen Formen," appeared in the Quarterly Journal of the Geological Society for 1847 †, in which it is stated that *Fenestella antiqua* was found in blocks of Carboniferous Limestone fallen from the top of Mount Misery, Bären Island.

1850. Dr. C. Grewingk in a work, 'Beitrag zur Kenntniss der orographischen und geognostischen Beschaffenheit der Nordwest-Küste Amerika's,' &c. ‡, gives in the first Appendix §, "On the Fossil Fauna and Flora," a list of fossils from Cape Thomson. An encrinital limestone is there mentioned containing *Lithostrotion basaltiforme* and *Flustra*; the latter name probably comprehends what we now know as *Fenestella*.

1852. During this year the late Mr. J. W. Salter contributed two papers devoted to Arctic palæontology. The first consisted of a Geological Appendix to Dr. P. C. Sutherland's work ‖, in which a number of fossils from the neighbourhood of Wellington Channel and other localities are described—amongst these a species of *Fenestella* with curved and zigzag interstices ¶, and another species of the same genus with small cells and only two to a fenestrule **.

The second of Mr. Salter's papers was an account of the Arctic Carboniferous fossils contained in Sir E. Belcher's 'Last of the Arctic Voyages' ††, and included only one species of Polyzoa, *Fenestella arctica*, Salter ‡‡, allied to *F. martis*, Fischer, and *F. crebrioculata*, De Vern., from Dépôt Point. This form occurs amongst Capt.

* Bull. de l'Acad. Royale des Sc. &c. de Belgique, t. xiii. 1846, pt. i. pp. 592–596.

† Q. J. G. S. iii. pt. ii. p. 48 ; also see Abhandl. k. Akad. Wissensch. zu Berlin aus dem Jahre 1846, p. 65.

‡ St. Petersburg, 8vo. § Page 270.

‖ Journal of a Voyage in Baffin's Bay and Barrow Straits in the years 1850–51, performed by H.M. Ships 'Lady Franklin' and 'Sophia.' London, 8vo, 1852, vol. ii. App. p. ccxvii.

¶ P. ccxxvii, t. 6. f. 1. ** P. ccxxvii.

†† London, 1855, 2 vols. 8vo, vol. ii. pp. 377–391, t. 36 ; reprinted, with remarks, in the 'Manual and Instructions for the Arctic Expedition,' 1875, p. 551. ‡‡ P. 385, t. 36. f. 8.

Feilden's fossils, and is one of much interest; I have some doubts as to the propriety of referring it to the genus *Fenestella*. It is probably identical with that noticed in the preceding abstract as possessing curved and zigzag interstices.

1853. The 'Quarterly Journal' for this year contains a third paper by Mr. Salter, "On Arctic Silurian Fossils"*, attached to Dr. Sutherland's memoir "On the Geological and Glacial Phenomena of the coasts of Davis Strait and Baffin's Bay"†. The fossils are Upper Silurian in character, and chiefly from the neighbourhood of Wellington Strait. At the S.W. end of Seal Island, a rock in Baring Bay, a white crystalline limestone yielded a small species of *Fenestella*, figured in Sutherland's Journal ‡; the same species is also probably found at Leopold Island, Barrow Straits.

1855. Mr. A. K. Isbister contributed a paper to this year's 'Quarterly Journal,' "On the Geology of the Hudson's Bay Territories, and portions of the Arctic and North-western Regions of America," &c. §, in which he gave copious lists of Upper Silurian fossils from the Wellington Channel district, Baring, Lake Winnipeg, and the Slave Lake, and also from the Carboniferous series of the Mackenzie. One species of *Fenestella* is mentioned.

1856. In the 'Report of the British Association' for 1855 || appeared a paper by Mr. Salter, "One some Additions to the Geology of the Arctic Regions," which contains a good general account of Arctic geology. The coast-line of Albert Land, in lat. 78° N., is strewn with blocks containing numerous fossils, which "prove to be all Carboniferous types; corals of the genera *Clisiophyllum*, *Zaphrentis*, *Lithostrotion*, *Stylastræa*, *Michelinia*, Brachiopod shells, *Producti*, and Spirifers, with *Fenestella* &c." ¶.

1858. An interesting appendix to a paper by Rear-Admiral M'Clintock was given by the Rev. Samuel Haughton, F.R.S., entitled "Descriptions of the Plates to illustrate the Geology of Captain M'Clintock's Ice Travels," in the 'Journal of the Royal Dublin Society'**. A figure is given of a unique specimen from Garnier Bay, Griffith's Island, "probably a Bryozoan coral" ††.

1859. This form is again referred to as an "undescribed Bryozoan zoophyte" by Dr. Haughton in his "Geological Account of the Arctic Archipelago, drawn up principally from the specimens collected by Captain F. L. M'Clintock from 1849 to 1859" ‡‡.

1860. The foregoing paper also appeared in the 'Journal of the

* Quart. Journ. Geol. Soc. ix. p. 312; and reprinted in the 'Manual and Instructions for the Arctic Expedition,' 1875, p. 531.
† *Ibid.* p. 296.
‡ T. 6. f. 1.
§ Quart. Journ. Geol. Soc. xi. p. 497.
|| Pt. 2, p. 211.
¶ *Loc. cit.* p. 212.
** Vol. i. p. 239.
†† *Loc. cit.* p. 243, t. 7. f. 6.
‡‡ M'Clintock's 'Narrative of the Discovery of the Fate of Sir J. Franklin,' &c., Append. iv. p. 372.

Geological Society of Dublin'*, where the fossil in question is stated to be of Silurian age, and is called an undescribed Bryozoan zoophyte.

In Mr. J. Lamont's "Notes about Spitzbergen in 1859"† an appendix on the specimens is given‡, wherein is recorded the occurrence of rounded fragments of grey compact limestone in Ryke-Yse Islands, and of fragments of argillo-siliceous dark grey rock at an island in Bell Sound, containing *Fenestellæ* and corals.

Mr. J. W. Salter also contributed some remarks § on Mr. Lamont's paper. The Fenestellidæ from the island in Bell Sound, mentioned by the latter, consist, according to Mr. Salter, of two species of *Fenestella*, "one with very large meshes." From an undefined locality there is also recorded "a new genus, in all probability of the Fenestellidæ, consisting of thick stems branching regularly from opposite sides, the smaller branches also opposite, and coalescing with their neighbours so as to form a quadrangular network. But for this coalescence, it might be a gigantic *Thamniscus* or *Ichthyorhachis*." The general facies of the fossils was thought to be Carboniferous; and the size of both the shells and Polyzoa Mr. Salter considered to be remarkable, the latter being "larger than the corresponding species in our own Mountain Limestone." Three localities are represented, viz. Bell Sound at 400 feet above sea-level, island in Bell Sound at 250 feet, and Black Point, south-east angle of Spitzbergen.

1861. The above remarks were contributed by Mr. Salter as an appendix to Mr. Lamont's work, 'Seasons with the Sea-Horses,' &c.‖, in almost identical words.

1874 and 1875. In the 'Neues Jahrbuch' for 1874, Dr. F. Toula gave a list of fossils ¶ from Bell Sound and Axel Island, Spitzbergen, which were described in detail in the 'Jahrbuch' for the following year (1875) under the title "Permo-Carbon-Fossilien von der West-Küste von Spitzbergen"**. The Polyzoa described in this memoir are the following; and, as it is an important paper, I shall give a few detailed notes on the species:—

1. *Fenestella*, sp., allied to *F. Geinitzii*, D'Orb., and *F. tenuifila*, Phill.; the stems are thicker than the branches, and there are three cells on each side the former within the space comprised by each fenestrule or mesh. Dr. Toula thinks this may be new.

2. *Fenestella*, sp., allied to *F. retiformis*, Schl., and *F. carinata*, M'Coy.

* Vol. viii. p. 196. This and the foregoing papers by Prof. Haughton were reprinted in the 'Manual and Instructions for the Arctic Expedition,' 1875, pp. 442–550.

† Quart. Journ. Geol. Soc. xvi. p. 428.

‡ *Loc. cit.* p. 436.

§ "Note on the Fossils from Spitzbergen," *loc. cit.* p. 439.

‖ London, 8vo, p. 307.

¶ "Verzeichniss der von ihm beschriebenen Versteinerungen aus Spitzbergen," p. 964.

** Pp. 225–264, pls. 5–10.

3. *Polypora*, sp.; a form branching less regularly than *P. dendroides*, M'Coy, but otherwise closely corresponding with the latter.

4. *Polypora*, sp., allied to *P. fastuosa*, De Koninck; possesses oval fenestrules, thin striated dissepiments, and four cells in each oblique cross row.

5. *Polypora grandis*, Toula; a large and boldly formed species, with flat interstices carrying oblique cross rows of five or six cells in each; the dissepiments are thin, oblique, and striated.

6. *Polypora*, sp., with a funnel-shaped frond, resembling in some points *P. biarmica*, Keyserling; the cells, however, are three or four in each oblique cross row.

7. *Ramipora*, Toula (nov. gen.).—Under this name Dr. Toula separated a *Synocladia*-like polyzoan, in which a main stem gives off large branches at the same level on opposite sides, trending upwards. These lateral or secondary branches themselves give rise to shorter and slighter dissepiments on each side, which, projecting towards one another, meet and form an arched fenestrule. Both the main stem and branches are keeled on each face of the polyzoarium, but the cells open only on one, and are placed in longitudinal rows. The type and only species described is *R. Hochstetteri*, Toula. I shall have occasion to refer again to this form.

8. *Phyllopora Laubei*, Toula; a characteristic *Phyllopora*, in which the reticulation is coarser or larger than in *P. Ehrenbergi*, King.

1875. Another excellent paper by Dr. Toula, "Eine Kohlenkalk-Fauna von den Barents-Inseln (Nowaja-Semlja, N.W.)" *, contains numerous descriptions of Polyzoa, which it is necessary to notice in detail. He there describes:—

1. *Glauconome*, sp., near *G. pulcherrima*, M'Coy, and *G. trilineata*, Meek, from Höfer Island. It is a mere fragment.

2. *Polypora biarmica*, Keyserling, var. Specimens from Höfer Island are considered by Dr. Toula to be a variety of Keyserling's Russian form. American specimens from Nebraska city were referred to this species by Dr. Geinitz, for which the latter was rather severely criticized by the late Mr. F. B. Meek; however, Dr. Toula appears to consider that even the American variety may be brought to agree with the typical form by the aid of the Nova-Zembla specimens.

3. *Polypora fastuosa*, de Koninck, from Höfer Island and Scheda Island, is considered by Dr. Toula to be allied to *P. bifurcata*, Keyserling.

4. *Polypora laxa*, Phillips, from Scheda Island; a form possessing an irregular network, like that of Phillips's species.

* Sitz. d. k. Akad. d. Wissenschaften zu Wien, 1875, lxxi. pp. 562–574.

5. *Polypora subquadrata*, Toula; a species not possessing any peculiarly distinctive characters.

6. *Polypora*, sp., near *P. marginata*, M'Coy. It appears to differ from the type in the absence of the particularly characteristic broad flat margin of the branches &c.

7. *P. crassipapillata*, Toula, from Höfer Island, as pointed out by the author, appears to be closely related to *P. papillata*, M'Coy. I much doubt if it is more than a variety.

8. *P. pustulata*, Toula, near *P. pustulata*, mihi. A well-marked and peculiar form from Höfer and Scheda Islands. It is compared by Dr. Toula with *P. fastuosa*, De Koninck. There is a very marked difference between the size of corresponding portions in the respective species.

9. *Polypora*, sp., near *P. dendroides*, M'Coy. The same form mentioned by the author in his paper on Spitzbergen in the 'Neues Jahrbuch,' previously referred to.

10. *Archimedes arctica*, Toula. The extension of this peculiar subgenus of *Fenestella* into the rocks of the Arctic regions is an interesting fact, as it appears to have hitherto been found chiefly in the Warsaw and Keokuk limestones of Illinois, Indiana, and Missouri. Höfer Island.

11. *Fenestella retiformis*, Schlotheim, Barents Island; a Permian form; also found in Spitzbergen rocks (*Toula*).

12. *Fenestella*, sp., near *F. Shumardi*, Prout. Under this name are grouped several forms—one not easily distinguished from *F. flabellata*, Phillips; another related to *F. plebeia*, M'Coy; a third having the cup-like form and anchoring rootlets of *F. membranacea*, Phill.; a fourth nearer to the typical *F. Shumardi*, Prout, but for which, from the minute nature of the pores and fenestrules, Dr. Toula proposes the varietal name of *minima*. A fifth and last form is included, possibly allied to *F. carinata*, M'Coy. So far as I understand Dr. Toula's remarks, these all appear to be regarded as varieties of one form.

13. *F. inconstans*, Toula. A form in which there appears to be little division between the interstices and dissepiments, and the fenestrules are irregular in outline. The cells occur in circlets round the fenestrules in a rather peculiar and uncommon manner, giving to the polyzoarium, as Dr. Toula himself remarks, somewhat the appearance of a *Phyllopora*, King.

14. *F. undulata*, Phill.? Fragments of a form somewhat allied to this British species were noticed.

15. *F. tenuifila*, Phill. Specimens exhibiting a very delicate network render it probable that this species also occurred in the Barents-Island collection.

16. *F. Goldfussiana*, De Koninck.

In addition to the foregoing, Dr. Toula describes amongst the Actinozoa of his paper two species which I consider to be probably Polyzoa; they are:—

17. *Rhombopora* (*Ceriopora*) *bigemmis*, Keyserling.

18. *Millepora* (*Pustulopora*) *oculata*, Phillips.

1876. Prof. A. E. Nordenskiöld, in his 'Sketch of the Geology of Ice Sound and Bell Sound, Spitzbergen'*, gives a note on the Carboniferous-Limestone fossils collected by Dr. Lindström during his expedition of 1868, from which it appears that out of a total of sixty-three species, seven were Polyzoa. Nordenskiöld concludes that the strata yielding the fossils are of Mountain-Limestone age, but containing an admixture of species occurring in other countries only in the Permian.

1878. In concluding this bibliographical notice of hitherto described Arctic Palæozoic Polyzoa, so far as known to me, I have to notice the species recorded by my friend Dr. J. J. Bigsby in his recently issued 'Thesaurus Devonico-Carboniferus.' Within the pages † of this remarkable epitome of the organic remains of the Devonian and Carboniferous epochs is given a list of fossils from Feilden Isthmus, lat. 82° 43′ N., collected by Captain Feilden and communicated by my father. They are:—

Fenestella arctica, *Salter*.
—— cribrosa, *Hall*.
—— intertexta, *Portlock* ?
—— sp., near F. bicellulata, *mihi*.
Polypora biarmica, *Keyserling*.
—— grandis, *Toula*.
—— megastoma, *De Koninck*.
Ramipora Hochstetteri, *Toula*.

Description of the Species.

Genus Fenestella (Miller), Lonsdale, 1839.

Fenestella, Murchison, Sil. System, p. 677; restricted by King, Permian Foss. England, 1850, p. 35.

Fenestella ? arctica, Salter.

Fenestella arctica, Salter, Belcher's Last of the Arctic Voyages, vol. ii. 1855, p. 385, t. 36. f. 8.

Sp. char. Polyzoarium flat, in one plane; interstices thicker than broad, zigzag, angular on the obverse face, rounded on the reverse or non-celluliferous face; dissepiments short, quite horizontal, of equal breadth with the interstices, and similar in character; fenestrules hexagonal, large, broad; here and there one may be found smaller and more irregular than the others, but, as a rule, they retain their size and form with great regularity; cells opening on the angular faces of the zigzag dissepiments in two alternating lines, one on each side; reverse smooth to the naked eye, but finely striated when magnified.

* Geol. Mag. dec. 2. iii. p. 63.

† P. 426 *f*.

Obs. The zigzag interstices give to this species a peculiarly distinctive character; whilst, as remarked by Mr. Salter, their size and great regularity, with that of the fenestrules and the almost vertical series in which the latter are disposed one under the other, render *F. arctica* a conspicuous species. Salter saw only the non-poriferous face; and, although I have the opposite or celluliferous in some of the present specimens, the characters are so obscured that I should not like to give any definite details; however, the obverse is strongly carinate, and the cells appear to be arranged in several rows on each side the keel, in a similar manner to the form I have described under the name of *Goniocladia cellulifera*; and if the reverse is rounded, as above stated, and not angular, it will not surprise me also if, as I have some reason to believe, *F.? arctica* should ultimately be proved to be a species of *Goniocladia.* This, however, is a question I cannot settle with the material at my disposal. Mr. Salter compared *F.? arctica* with *F. martis*, Fischer; but as I have not access to Fischer's rare 'Oryctographie,' I cannot enter into details on this point. Mr. Salter also compared *F. arctica* with *F. crebrioculata*, Vern., in which he states there is "neither so flat a surface nor such large perforations,"

Loc. Dépôt Point, Albert Land (*Salter*); Feilden Isthmus, lat. 82° 43′. In Carboniferous Limestone.

Fenestella, sp.

(Compare *F. cribrosa*, Hall, Pal. N. Y. 1862, ii. p. 166, t. 40 d. f. 3 *a* & *b*; Nicholson, Report Pal. Ontario, 1874, p. 106, f. 43 *a* & *b*.)

Obs. Although the single specimen amongst the Arctic fossils is only a decorticated fragment showing the basal layer, with projecting casts of the cells, still the characters are so marked and regular that I think there can be little doubt of the identity of the specimen in question. There are two cells in the length of every fenestrule on each side of the keel of the interstices, and one opposite the base of each dissepiment, characters which agree particularly well with those assigned by Prof. Nicholson to this species. *F. cribrosa* need not be confounded with a small form described by myself as *F. bicellulata*, in which there are also two cells to the length of each fenestrule; but they are invariably placed in the angles formed by the union of the dissepiments and interstices, and deeply indent the borders of the otherwise nearly square fenestrules. There is also an entire absence of the cell at the base of each dissepiment. *F. cribrosa* is probably closely allied to *F. Norwoodiana*, Prout*; but of this we unfortunately do not possess a figure. The normal condition of this species appears to be that of one cell at the base of each dissepiment, and one in the length of each fenestrule, although variation occasionally takes place. Prof. James Hall described the non-celluliferous face of *F. cribrosa* from the Niagara limestone (Upper

* Trans. St. Louis Acad. i. p. 233.

Silurian), and Prof. H. A. Nicholson a specimen, showing the cells, from the Hamilton group (Upper Devonian). The condition of the example in Capt. Feilden's collection does not enable me to add any further details.

Loc. Feilden Isthmus, lat. 82° 43′.

FENESTELLA, sp.

Obs. Amongst some finely preserved remains on the surface of a piece of limestone, two small fragments occur which bear a close resemblance to a species I described from the Scotch Carboniferous limestone as *Fenestella bicellulata* *. The essential characters are the oblong fenestrules, alternate in contiguous series, with two cells only to every fenestrule on each side the angular interstice, placed in the angles formed by the junction of the interstices and dissepiments. These characters are as strongly marked in the Arctic as in the Scotch examples; but the marked indentation of the sides of the fenestrules by the aperture of the cells, and the strong median keel, with its line of nodes visible in *F. bicellulata*, do not appear to be present in the Arctic form. Furthermore, the prominent mouths of the cells are also absent in the latter. A comparison may also be instituted with *Polypora intermedia*, Prout † (which, I think, should perhaps be more properly regarded as a *Fenestella*); but the fragments are small, and the preservation not all that could be desired, so that we can do little more than give a mere notice of such a form, to be used in future investigations. It must not be forgotten that Mr. Salter mentions the occurrence of a *Fenestella*, with only two cells in the length of the fenestrule, in Dr. Sutherland's collection.

Loc. Feilden Isthmus, lat. 82° 43′.

FENESTELLA, sp.

Obs. A specimen of a *Fenestella* with a fan-shaped polyzoarium has been split in two in a longitudinal direction; and as the external characters are not shown, specific determination is quite out of the question. The interstices and dissepiments were arranged in a very regular and definite manner; the former straight, narrow, and seldom bifurcating, the latter short and thin. The fenestrules enclosed by them are long and narrow, and the whole appearance of the polyzoarium recalls to us that of *F. plebeia*, M'Coy ‡, of our own Carboniferous rocks. The cells were, so far as I can make out, from four to six in the length of a fenestrule; in fact the whole aspect is that of *F. plebeia*. Had the cells been less in number it might also have been compared with *F. membranacea*, Phill.§

Loc. Feilden Isthmus, lat. 82° 43′.

* Mem. Geol. Surv. Scotl. Explanation-sheet 23, 1874.
† Trans. St. Louis Acad. i. p. 272, t. 15. f. 5.
‡ Synop. Carb. Foss. Ireland, 1844, t. 29. f. 3.
§ Synop. Carb. Foss. Ireland, 1844, p. 202 (M'Coy's description).

Genus Polypora, M'Coy, 1844.
(Synop. Carb. Foss. Ireland, 1844, p. 206.)

Polypora grandis, Toula?

Polypora grandis, Toula, N. Jahrbuch, 1875, p. 230, t. 9. f. 7.

Sp. char. Interstices flat, broad, and increasing in size previous to bifurcation; dissepiments thin, usually oblique and striated; fenestrules large, elongate obliquely and rhomboidal, narrow, occasionally irregular; apertures of the cells arranged on the interstices in oblique rows, five or six to the row.

Obs. The broad flat interstices and narrow, much elongated fenestrules will, I think, be sufficient to separate the two specimens I have recorded under this name and those I have placed under *P. fastuosa*, De Koninck. Whether they are *P. grandis*, Toula, however, is a point open to discussion. The specimens in question agree with Dr. Toula's description and figures in the broad, flat, conspicuous interstices and narrow elongated fenestrules; but, on the other hand, the dissepiments are not so regularly oblique in our form, but are, for the most part, horizontal. As I am averse to creating a new species when a reference to a known one can possibly be made, even by a slight extension of its characters, I provisionally place these specimens under Dr. Toula's species.

Polypora grandis, in the size of its interstices and fenestrules, is allied to *P. (Retepora) laxa*, Phill.*, and again, irrespective of the generic differences, to *Fenestella coassa*, M'Coy. In *P.? laxa*, however, the network of the polyzoarium is much more irregular than in *P. grandis*, although this is less marked in Phillips's second and later figure of his species†.

Loc. Feilden Isthmus, lat. 82° 43′.

Polypora megastoma (De Koninck?).

Fenestella megastoma, De Kon. Quart. Journ. Geol. Soc. 1863, xix. p. 5, t. 2. f. 3.

Sp. char. Polyzoarium expanding, inclined to be irregular; interstices subparallel, slightly thicker than the dissepiments, bifurcating at intervals, with very little apparent thickening at each bifurcation; dissepiments horizontal, subalternate in contiguous rows, here and there nearly opposite; fenestrules parallelogrammic, with rounded angles, longer than wide, sides not indented or overhung by the cell-apertures; cell-apertures numerous, arranged regularly in quincunx and confined to the interstices; reverse striate.

Obs. I cannot find any more fitting reference for the form represented than Prof. de Koninck's Indian species. One of the specimens I so refer is of about the same dimensions as, the other somewhat smaller than the Indian form; but in both there are to be observed the essential characters assigned by Prof. de Koninck to his species—the interstices and dissepiments of equal dimensions,

* Geol. Yorksh. 1836, ii. p. 199, t. 1. f. 26–30.
† Pal. Foss. Devon, 1841, p. 23, t. 12. f. 34.

the parallelogrammic fenestrules with rounded angles, the striated reverse, and with it all a somewhat irregular appearance. If my reference to Prof. de Koninck's form is correct, it will necessitate the transference of the species from the genus *Fenestella* to *Polypora*; for although the state of preservation is not good, still there is quite enough evidence to show that it is a *Polypora*, possessing the above characters in common with *F. megastoma*, De Kon.; and it must be borne in mind that the celluliferous face of the latter was unknown to Prof. de Koninck.

Very closely approaching to *P. megastoma*, De Kon., is one of Dr. Geinitz's figures* of *P. marginata*, M'Coy; but I am sorry that I cannot agree with so eminent an authority as Dr. Geinitz in his reference of the Nebraska forms to M'Coy's species; for the figures in question do not appear to me to agree with M'Coy's description at all.

Loc. Feilden Isthmus, lat. 82° 43′.

POLYPORA BIARMICA, Keyserling. (Pl. XXVIII. fig. 4.)

Polypora biarmica, Keyserling, Reise in das Petschora-Land, 1846, p. 191, t. 3. f. 10; Geinitz, Dyas, 1861, p. 117; Gein. Carbonformation u. Dyas in Nebraska, 1861, p. 68, t. 5. f. 13; Prout, Trans. St. Louis Acad. i. p. 450; Toula, Sitz. k. Akad. d. Wissensch. zu Wien, 1875, lxxi. p. 562, t. 3. f. 15, *a–c*; Miller, American Pal. Foss. 1877, p. 99.

P. spindet, Meek, Hayden's Final Report Geol. Survey of Nebraska, 1872, p. 155, t. 7. f. 6.

Sp. char. Polyzoarium widely funnel-shaped, expanding; interstices strong and robust, often bifurcating, as broad as, or broader than the fenestrules, and nearly flat on the celluliferous or obverse face, of less breadth on the reverse and more convex; dissepiments short and narrow on the obverse, sometimes becoming almost lost, but on the reverse they are longer and wider and on the same level with the interstices, whilst on the obverse they are somewhat below the latter; fenestrules variable in outline on the obverse, funnel-shaped, increasing in breadth towards the reverse, where they are, as a rule, quite circular or sometimes a little elongated; on the obverse the fenestrules are, as a rule, very narrow and sometimes quite slit-like, but always with the sides indented by the apertures of the cells: apertures of the cells circular, arranged in oblique rows on the interstices and devoid of projecting or prominent margins; the normal number in each row is three, sometimes four, and immediately before bifurcation of the stem takes place the enlarged dissepiment may carry six.

Obs. The form which I have assumed to be *P. biarmica*, Keyserling, is a most interesting one, from the peculiar change the polyzoarium appears to undergo with age and increased growth. The obverse and reverse differ so materially in appearance that they might easily be mistaken for distinct species, were it not for

* Carbonformation und Dyas in Nebraska, t. 5. f. 2.

their constant occurrence together in close proximity, and also that some of the fragments are so fractured as to show the gradual passage from the broad flat interstice of the obverse to the narrower and more convex stems of the reverse. The broad depressed interstices are well shown in the enlargement of Count von Keyserling's figure and in that given by Dr. Geinitz. The fenestrules, as seen on the obverse face, are nearly elliptical; but there is apparently a tendency to close up caused by a widening-out of the depressed interstices, so that their form becomes more and more contracted laterally and slit-like, till at last almost complete coalescence of the interstices takes place and the fenestrules nearly disappear. Furthermore, on some parts of the polyzoarium the apertures of the cells appear to close up; and when this takes place, in addition to the impinging of the interstices on the fenestrules, we have presented to us a surface unbroken except by the remains of a few obscure slits arranged in vertical lines. On the other hand, when the cells remain open, the apertures are clear and well marked, but without raised margins. The dissepiments on the obverse are very short, and as the gradual closing of the fenestrules takes place, their individuality is quite lost; they are sometimes celluliferous to the extent of one or two cells.

Now many of the points here mentioned, although not described by Keyserling and others, are nevertheless to be seen in their figures. For instance, the broad, almost flat interstices, the gradually disappearing dissepiments, and the obscured fenestrules are all, to a certain degree, discernible in the before-mentioned enlargement of Keyserling's figure. After a lengthened examination of the specimens, and careful consideration of all the facts, I believe *Polypora biarmica* is better fitted for the reception of several of the Arctic Polyzoa possessing the above characters than any other figured species known to me. The specimens in question resemble *P. biarmica* in the breadth of the interstices being equal to and sometimes greater than that of the fenestrules, in the number and arrangement of the cells and in their plain margins, in the oval form of the fenestrules, and, lastly, in the fact that, as Keyserling remarks, the latter are sometimes so narrow as to be almost overlooked, a point which I consider quite coincides with the closing of the fenestrules which I have above described. On the other hand, the sides of the fenestrules are certainly rendered irregular by the impingement over them of the lateral row of cell-apertures on each side, which I do not find mentioned or figured by those authors who have written on this species. Again, in our specimens there is certainly no trace of the obscure and slightly granular wrinkles of the reverse mentioned by Keyserling; but, on the whole, I think the evidence is more confirmatory than otherwise of their relation to *P. biarmica*. The best of our specimens, exhibiting the reverse face, agrees exceedingly well, in the round or oval form of the fenestrules, with the figure of the specimens from Nova Zembla given by Dr. Toula, and to a certain extent with that of *Polypora Shumardiana*, Prout*; but it must be

* Trans. St. Louis Acad. i. p. 271, t. 16. f. 3.

observed, in conclusion, that the dimensions of the specimens now under consideration are greater than those of any of the figures quoted in the foregoing synonymy.

P. biarmica was originally described by Keyserling from Petschora-Land; by Geinitz from beds in Nebraska, which he considered to be of Permo-Carboniferous age (Dyas); by Prout from the Upper Archimedes limestone of Chester, Illinois; by Meek from the Nebraska-city section of the Nebraska Upper Coal-measures (=Dyas, Geinitz); and by Dr. Toula from Carboniferous beds at Barents Island, Nova Zembla. Some difference of opinion existed between Dr. Geinitz and Mr. Meek as to the identity of the Nebraska fossils with *P. biarmica*, Keyserling; but on this point I am inclined to agree with Dr. Toula, that the various forms may be all included under the one name.

Loc. Feilden Isthmus, lat. 82° 43′.

POLYPORA, sp.

Obs. A species possessing strong interstices, with oval, almost round fenestrules; in fact the interstices and dissepiments at times almost lose their individuality, and with the round fenestrules give to the polyzoarium a decidedly *Phyllopora*-like appearance. Two of the specimens exhibit the non-celluliferous face, with the bases of the cells shown through the abrasion of the basal layers. The other specimen is a badly preserved example of the obverse face; the cells are arranged in three oblique rows on the dissepiments, increasing in number at the points of bifurcation of the latter, and apparently separated by vertical, obscure, wavy ridges. The specimens have some characters in common with those I have described in *P. biarmica*, but they are probably distinct. The dissepiments appear to be occasionally cell-bearing, and when so there is generally a large cell at the base of the dissepiment on each side. The vertical wavy ridges, and some other minor points, recall to us *Polypora tuberculata*, Prout*; but in this species the dissepiments are quite devoid of cells, whilst the oval or almost circular fenestrules again bring before us *P. Shumardiana*, Prout. The celluliferous dissepiments resemble those of *Fenestella ampla*, Lonsdale† (*Protoretepora ampla*, De Koninck‡); and, in fact, one specimen in particular recalls to us this species very forcibly, with this exception, that in the Australian form the fenestrules are more elongated and more truly oval than in the Arctic individuals.

The specimens at my disposal are not of sufficient size to enable me to form an opinion whether the celluliferous face is internal or external; if the former, the resemblance to *P. ampla* would be strengthened, and the reference of them to the genus *Protoretepora* indicated, although one of the characters possessed by our specimens,

* Trans. St. Louis Acad. i. p. 449, t. 18. f. 3.

† Strzelecki's Phys. Descript. N. S. Wales, 1845, p. 268, t. 9. f. 3.

‡ Foss. Pal. Nouv.-Galles du Sud, 1877, pt. 3, p. 180, t. 8. f. 5, *a–d*. Prof. de Koninck includes in his genus *Protoretepora*, besides *F. ampla*, Lonsdale, *Polypora Shumardiana*, Prout, and some other forms.

the occasional celluliferous dissepiments, has an opposite tendency, according to the diagnosis of *Protoretepora* as laid down by Prof. de Koninck.

Loc. Feilden Isthmus, lat. 82° 43′.

Genus Ramipora, Toula, 1875.

New Genus, Salter, Quart. Journ. Geol. Soc. 1860, xvi. p. 441.
Ramipora, F. Toula, N. Jahrbuch, 1875, p. 230.

Gen. char. Polyzoarium reticulate, spreading, consisting of a stem or interstice, seldom, if at all, bifurcating, and primary branches, about equal to it in size, arising from the former at regular intervals and on the same level with one another. The primary branches do not show any trace of alternation with one another on opposite sides of the stem, but curve upwards from each side of the latter; both are divided by an obtuse median keel. The primary branches are united with one another by smaller secondary branches or dissepiments, which likewise arise opposite one another, and either curve upwards, meeting one another in the middle line, or are continued direct from branch to branch without any arching. The fenestrules thus enclosed are either irregularly and obliquely quadrangular, or of a peculiar six-sided or double V-shaped form. Both the stem and the primary and secondary branches are celluliferous, but on one aspect of the polyzoarium only, the obverse. All apertures arranged in longitudinal series on both sides the median keels. Reverse of the polyzoarium keeled, but not celluliferous.

Obs. The genus *Ramipora* was established by Dr. Toula for a peculiar form of Permo-Carboniferous Polyzoa from Spitzbergen, related to *Synocladia*, King, *Ptylopora* (Scouler), M'Coy, and *Glauconome* (Goldf.), Lonsdale. It appears to differ from the first of these in the absence of dichotomization of the stem and primary branches, so far as the remains of it are known to us; in the bilateral symmetry of the latter; thirdly, in the fact that the cells all open on the same plane on each side the median keels, whereas in *Synocladia* the stems and branches are divided longitudinally by several carinæ, between which the cell-apertures occur. Again, in *Ramipora* both aspects of the polyzoarium are carinate, but in *Synocladia* only one. Lastly, in *Synocladia* the dissepiments all appear to be regularly celluliferous, but in *Ramipora* this does not appear to hold good to the same extent; it is, however, a character of lesser importance. In the presence of the principal thick stem and bilaterally symmetrical primary branches we have characters uniting *Ramipora* and *Ptylopora*; but the arrangement of the cells in the two genera is wholly different, and the form of the cross bars or dissepiments, as a rule, distinct. In *Glauconome*, Lonsdale (= *Acanthocladia*, King), it will be remembered, there is a stem giving off lateral branches, alternate or subalternate with one another on opposite sides, and trending upwards at various angles, upon which the cells are variously arranged according to the species; but there does not appear to be any union by cross bars or dissepiments between these branches, and in consequence the polyzoarium is non-fenestrate. In the latter character we have an essential difference between *Ramipora* and *Glauconome*. Again, in the latter the polyzoarium is carinate only on one aspect, unlike that of *Ramipora*; there is likewise a different arrangement of the cells, irrespective of other minor points which might be entered upon. In the genus *Tænio-pora*, Nicholson*, there is a bicarinate polyzoarium, as in *Ramipora*; but it forms flattened linear expansions, and branches dichotomously, the branches proceeding from the main stems alternately. Lastly, the polyzoarium in *Goniocladia*, mihi, is carinate on the celluliferous face only, and in the general arrangement of the cells resembles *Ramipora*; but in my genus there is no clear division into interstices and dissepiments, and the meshes or fenestrules are all more or less irregular points, which at once separate it from Dr. Toula's form. One of the most marked characters of *Ramipora* is the upward arching of the secondary branches or dissepiments; and the resulting peculiarly formed fenestrules are of *Synocladia*-like character. It appears to me that *Ramipora* stands in about the same relation to *Synocladia* that *Ptylopora* does to *Fenestella*; *i. e.* in *Ramipora* we have an aberrant *Synocladia*, in which there is one chief stem giving off branches, assuming the typical character, more or less, of the latter; whilst in *Ptylopora* we see, to all intents and purposes, a *Fenestella*-like expansion spreading out on each side of a well-marked median rib. Again, another interesting link between several already established genera is Prof. de Koninck's recently described *Dendricopora*†, a close ally of *Ptylopora* (Scouler), M'Coy, but differing from the latter in the presence of a number of lateral branches resembling the main stem or rib, in addition to the secondary ones forming the plumose expansion as in *Ptylopora*. The generic value of *Dendricopora* very much depends upon the characters of the perfect polyzoarium in *Ptylopora*; for, so far as I am aware, we at present know only the fragment figured by M'Coy. A glance at the respective figures of *Ramipora* and *Dendricopora* will show the distinction between them. Were it necessary to pursue this subject further, we might institute a comparison with M'Coy's genus *Ichthyorhachis*.

In concluding these remarks on *Ramipora*, I think it is quite within the bounds of possibility, indeed probability, that it was a specimen of this Mr. Salter had before him when he wrote as follows concerning one of Mr. Lamont's fossils:—"A new genus, in all probability of the Fenestellidæ, consisting of thick stems branching regularly from opposite sides, the smaller branches also opposite, and coalescing with their neighbours so as to form a quadrangular network," &c. The fossils described by Dr. Toula, accompanying *Ramipora*, are evidently of a Permo-Carboniferous facies; the Polyzoa, with the exception of *Phyllopora Laubei*, Toula, possess a

* Geol. Mag. 1874, dec. 2, i. p. 121; Rep. Pal. Prov. Ontario, 1874, i. p. 107.
† Foss. Pal. Nouv.-Galles du Sud, 1877, pt. 3, p. 169, t. 8. f. 4.

decidedly Carboniferous aspect; whilst the Brachiopoda, on the other hand, such as *Productus horridus*, indicate Permian affinities.

One species only has been described, *R. Hochstetteri*, Toula.

Ramipora Hochstetteri, Toula.

Ramipora Hochstetteri, Toula, N. Jahrbuch, 1876, p. 230, t. 10. f. 1, *a* & *b*.

Obs. It is unnecessary to describe this further, as the foregoing characters will suffice for it. There are in the collection four specimens which I refer to *R. Hochstetteri*; two of them may, however, form a second species, judging from the less compact manner in which the polyzoarium is held together; but the material is insufficient and the preservation indifferent.

This species strongly resembles *Synocladia* from the Permian rocks; but the bilateral connecting processes or branches in that genus are more arcuated than in *R. Hochstetteri*, and the main or chief and also the secondary branches in *Ramipora* are much more delicate.

Loc. Toula's specimens were collected on the west coast of Spitzbergen (Axel Island); Captain Feilden's at Cape Joseph Henry, lat. 82° 50′.

Genus Phyllopora, King, 1849.

(Annals Nat. Hist. 1849, iii. p. 389; Permian Foss. England, 1850, p. 40.)

Phyllopora, sp.?

Obs. A few fragments are mixed with the other Polyzoal remains on the black limestone previously mentioned, which I believe to be referable to *Phyllopora*, King. The portions of the frond or polyzoarium remaining consist of rounded interstices anastomosing one with the other, after the manner of *Phyllopora*, and producing a series of oval or rounded-oval meshes or fenestrules. The cells are numerous, with prominent margins, and are scattered over the surface of the so-called interstices; for there is no proper division into celluliferous interstices and non-celluliferous dissepiments, hence the reference to *Phyllopora*. Did the polyzoarium possess true non-celluliferous dissepiments there would exist a close resemblance between the Arctic form and *Polypora gracilis*, Prout*, of the Keokuk group of Illinois. So far as I can judge from the fragments I have seen, the resemblance to *P. Laubei*, Toula, from Nova Zembla†, is only a general one.

Loc. Feilden Isthmus, lat. 82° 43′.

Class BRACHIOPODA.

Only five genera with twelve species of this group occur in the Carboniferous collection. The genera are *Spiriferina*, *Spirifera*, *Productus*, *Streptorhynchus*, and *Rhynchonella*. The two genera

* Illinois Geol. Report, ii. t. 21. f. 1. † N. Jahrbuch, 1875, t. 9. f. 1.

Spirifera and *Productus* contain (as might be expected) the greatest number of individuals, yet the species are few—in *Spirifera* four, *Spiriferina* one, *Productus* five, *Streptorhynchus* one, and *Rhynchonella* one. All the species are British except *Spirifera Grimesi*, an American form, the others named having a wide distribution. Feilden Isthmus must be a prolific locality, if thoroughly searched; for it is evident that a rich Carboniferous-limestone fauna reaches this high latitude, 82° 43′, and would indicate that the true Coal-measures may be under the waters and ice of the Polar sea. Four genera with ten species of Polyzoa from the same locality accompany the Brachiopoda; but only one or two Corals came home in the collection—a *Syringopora* and a *Lithostrotion*, evidently from the same beds.

Genus Spirifera, Sow. 1815.

Spirifera duplicicosta, Phill.

Spirifera duplicicosta, Phill. Geol. York. vol. ii. p. 218, t. 10. f. 1; Dav. Monogr. Carb. Brach., Pal. Soc. p. 24, t. 3. f. 7–10, t. 4. f. 3, 5–11.

This variable species corresponds with the description and figures given by Mr. Davidson in his valuable Monograph upon the Carboniferous Brachiopoda (*loc. cit.*). It does not appear to be common in the Arctic rocks, only three specimens occurring in the collection. One specimen resembles also *Spirifera striata* (Martin), which is a closely allied species. Keyserling has described a species (*Spirifer fasciger*) from Petschora Land (Wissenschaftl. Beobacht. Petschora-Land, t. 8. f. 3), which certainly is the same as our British form and the *Spirifera duplicicosta* brought from Feilden Isthmus.

This species is common and abundant, in space and time, through the Carboniferous series; occurs everywhere in Britain, and in many places in Ireland, Belgium, &c.

Loc. Feilden Isthmus, lat. 82° 43′, in rough grey limestone.

Spirifera, sp., allied to S. Grimesi, Hall, Geol. Iowa, vol. i. pt. 2, p. 604, t. 14. f. 1–5. (Pl. XXV. fig. 5.)

We only possess a portion of the ventral valve of this species, which admirably shows the muscular impression; in the ventral valve none of the outer shell occurs; therefore whether it can be referred to Hall's species is perhaps really doubtful. It appears to have had a strongly incurved umbo. Hall's specimen came from the Burlington Limestones of Iowa, lat. 40°. Captain Feilden's single ventral valve is from Feilden Isthmus, lat. 82° 43′, a latitudinal difference of more than 40°.

No description can be given of this portion of the shell, nor can I refer it to any other known species: comparison with Hall's figure (*loc. cit.*) will show the close affinity. I figure it, however, for the sake of reference and for the peculiarity of its great muscular system.

Loc. Feilden Isthmus, lat. 82° 43′.

Spirifera, sp., allied to S. lamellosa (M'Coy).

Cyrtia lamellosa, M'Coy, Syn. Carb. Foss. Ireland, p. 137, t. 21. f. 4.
Spirifera lamellosa, Dav. Mon. Brit. Carb. Brachiopoda, Pal. Soc. p. 36, t. 7. f. 17–22.

This shell (only one specimen) closely resembles M'Coy's species, to which I refer it. Our specimen does not satisfactorily show the scale-like imbricated laminæ owing to the surface being much denuded. The *Spirifera hysterica*, De Kon., and *Spirifera speciosa* (M'Coy), are, without much doubt, the same as our Arctic form. We regret having to record only one specimen of this species.

Loc. Feilden Isthmus, lat. 82° 43′.

Spirifera ovalis, Phill.

Spirifera ovalis, Phill. Geol. York. vol. ii. p. 219, t. 10. f. 5; Dav. Monogr. Carb. Brach., Pal. Soc. p. 53, t. 9. f. 20–26.

This is an abundant shell at Feilden Isthmus, and one of the best defined species in the collection. Though it greatly resembles many forms of *Spirifera pinguis*, Sow., the deep and gibbous ventral valve and shallow sinus near the beak or umbo, as well as the short and small hinge-area, well characterize this shell. This species seems cosmopolitan, ranging from Belgium to Iowa; it is common to England, Scotland, and Ireland. It was not collected by M'Clintock during the voyage in search of Franklin, although much Carboniferous country was then passed over. It is one of the abundant shells in the collections of the Nares expedition.

Loc. Feilden Isthmus, lat. 82° 43′.

Genus Spiriferina*, D'Orbigny, 1847.

Spiriferina cristata (Schloth.) (? var. *S. octoplicata*, Sow.).

Spiriferina cristata (Schloth.); Dav. Monogr. Brit. Carb. Brach., Pal. Soc. p. 38, t. 7. f. 37–47; ib. p. 226, t. 52. f. 9, 10.

Only one specimen of this variable species has occurred in the 'Alert' collection. It has the nearest affinity to this of any *Spiriferina* known to me; one specimen, however, is scarcely reliable in so varying a group as the Spiriferidæ.

Loc. Cape Joseph Henry, lat. 82° 43′.

Genus Productus, Sowerby, 1814.

Productus semireticulatus (Martin).

Anomites semireticulatus, Mart. Petrif. Derb. p. 7, t. xxxii. f. 1, 2.
Productus scoticus, Sow. Min. Con. t. 69. f. 3.
P. sulcatus, Sow. *l. c.* t. 319. f. 2.
P. semireticulatus, Dav. Monogr. Brit. Carb. Brachiopoda, Pal. Soc. p. 149, t. 43. f. 1–11, t. 44. f. 1–4.

* The canals or perforations in the shells composing this genus, as well as the large elevated mesial septum in the ventral valve, separate it from *Spirifera*.

This variable and ubiquitous shell is tolerably abundant and occurs at Feilden Isthmus; the specimens agree in every particular with the Scotch, Russian, Spitzbergen, and American examples. It seems to be abundant in Illinois and Iowa with other widely spread species; finding this in lat. 82° 43′ tends to show clearly the connexion and continuity of the North-American Carboniferous fauna northwards and towards Grinnell Land. Our specimens, six in number, are from Feilden Isthmus, the most northerly land known.

Loc. Feilden Isthmus, lat. 82° 43′.

PRODUCTUS, sp., allied to PUNCTATUS, Martin, *Anomites*, Petrif. Derb. t. 37. f. 6.

Productus punctatus, Dav. Monogr. Brit. Carb. Brach., Pal. Soc. p. 172, t. 44. f. 9–16.

P. tubulispinosus, M'Chesney, Descr. New Sp. of Foss. from the Pal. Rocks of the Western States, p. 37.

So many forms have been referred to this species by British and foreign authors that some excuse may be made for referring a solitary specimen in a denuded state to so variable a shell. *Productus punctatus* and *Productus fimbriatus* much resemble each other, the lines of growth varying in both, being either wide apart or closely set; the hair-like spines on *Productus punctatus* are much more numerous than on *Productus fimbriatus*.

This shell occurs everywhere in Britain, is abundant on the Continent, and has received the name of *Productus tubulispinosus* by M'Chesney for specimens occurring in the Western States of America. Only two specimens have occurred in the Arctic collection. I doubt not the species.

Loc. Feilden Isthmus, lat. 82° 43′.

PRODUCTUS MESOLOBUS, Phill.

Producta mesoloba, Phill. Geol. Yorkshire, vol. ii. p. 215, t. 7. f. 12, 13; De Kon. Anim. Foss. du Terr. Carb. Belg. t. 12. f. 8; De Vern. Russia and Ural Mountains, vol. ii. t. 16. f. 8; Dav. Monogr. Carb. Brachiopoda, Pal. Soc. p. 178, t. 31. f. 6–9.

The projecting articulate expansions which constitute the attenuated cardinal extremities, and rounded lateral margins, characteristically distinguish this shell from all other species. The ventral valve is singularly gibbous at the umbo or beak. A few tubercles on the surface of the shell show the position of small tubular spines. Like most of the *Producti* in the collection, this is also a widely distributed species; it ranges from the Ural chain at Ilinsk to North America and the Polar regions, where it was collected by Captain Feilden at Feilden Isthmus, lat. 82° 43′.

PRODUCTUS FIMBRIATUS, Sow.

Productus fimbriatus, Sow. Min. Con. vol. v. p. 85, t. 459. f. 1; Dav. Monogr. Brit. Carb. Brach., Pal. Soc. p. 171, t. 33. f. 12–15.

We possess only one specimen of this species; it is a more finely marked variety than usual, nevertheless it can be no other than the above species. Like *P. mesolobus* this shell is found over the northern hemisphere, both in Europe and America, as far north as land is known. Collected by Capt. Feilden at Feilden Isthmus, lat. 82° 43′.

PRODUCTUS COSTATUS, Sow.

Productus costatus, Sow. Min. Con. vol. vi. p. 115, t. 560; De Verneuil, Russia and the Ural Mountains, vol. ii. t. 15. f. 13; Dav. Monogr. Carb. Brach., Pal. Soc. p. 152, t. 32. f. 2–9.

This is the most abundant and at the same time most variable species in the collection of the Carboniferous Brachiopoda, no less than fourteen specimens occurring from the beds at Feilden Isthmus. De Verneuil has noticed this species from many places in Russia; it also occurs at Visé, in Belgium. It is abundant in the Scotch and Irish Carboniferous Limestones. Settle, Richmond, and places in Northumberland also yield this species. Doubtless it must be very abundant in the limestones of Feilden Isthmus; it is the commonest form in the collection. In North America it is widely distributed through the limestones of Kansas, Missouri, Iowa, Illinois, and Indiana, also in Nova Scotia. We should therefore expect to find it extending northwards, in the original great spread of the Carboniferous series towards the Pole. With *P. Cora*, *P. Flemingii*, *P. punctatus*, and *P. semireticulatus* it has the widest range of any species on the American continent, and is associated with the last two at Feilden Isthmus.

Loc. Feilden Isthmus, lat. 82° 43′.

PRODUCTUS WEYPRECHTI ?, Toula.

Productus Weyprechti ?, Toula, Sitzungsberichte der kais. Akad. der Wissenschaften in Wien, p. 138, t. 1. f. 4.

The determination of this shell has given me much trouble. I can refer it to no other than the above species of Toula's. Much as it resembles some forms of *P. costatus*, it is not, however, that species, the sulcus in the ventral valve being deeper and wider in proportion, and extending along the central portion of the valve in nearly uniform width and depth. It may readily be taken for *Productus horridus*, from the Permian series; but the greater depth and squareness of the ventral valve, also the pronounced sulcus and apparent greater solidity of the shell, remove it from that species. When, however, we know the extreme variations these shells (especially *P. horridus*) undergo, and only three imperfect specimens are in the collection, it is not an easy matter to determine their specific identity. I refer them, however, to one or other of the above species, *P. Weyprechti* or *P. horridus*. Toula's specimens came from Spitzbergen, and were collected during the Austrian expedition to the Polar regions.

Loc. Cape Joseph Henry, lat. 82° 50′.

Genus Streptorhynchus, King, 1850.

Streptorhynchus crenistria (Phill.).

Spirifera crenistria, Phill. Geol. Yorksh. vol. ii. t. 9. f. 6.

Orthis umbraculum, Portlock; De Kon. Anim. Foss. du Terr. Carbon. Belg. p. 222, t. 13. f. 4–7.

Strophalosia striata, Morris.

Orthis keokuk, Hall, Report Iowa, t. 19. f. 5.

Streptorhynchus crenistria, Dav. Monogr. Carb. Brachiop., Pal. Soc. p. 124, t. 26. f. 1, t. 27. f. 1–5, t. 30. f. 14–16.

No more variable shell is known in the Upper Palæozoic rocks than the species under notice. It is also cosmopolitan, occurring almost everywhere in the European and American Carboniferous rocks. Only two specimens are known to me in the collection; but there is no doubt about them. In North America it ranges through Iowa, Illinois, Indiana, Ohio, Tennessee, and Nova Scotia; and occurs everywhere in Britain. Its varieties, *Strept. arachnoides*, *S. senilis*, and *S. radialis*, are common in the British Carboniferous rocks, also in France and Belgium.

Few shells have received more careful study than this species, owing to its extreme variation and universal distribution. It is also one of the few species connecting the Upper Silurian, Devonian, and Carboniferous group of rocks. As a Carboniferous form it ranges through every stage and division of these rocks, and in every country where developed, each author recognizes it under a different name. Spitzbergen and Australia, India and America, Britain and Europe, all lay claim to *Streptorhynchus crenistria*. Now we obtain it from the limestones of Feilden Isthmus, lat. 82° 43′.

Captain Feilden's specimens were collected at Feilden Isthmus, lat. 82° 43′.

Genus Rhynchonella, Fischer, 1809.

Rhynchonella pleurodon (Phill.).

Terebratula pleurodon, Phill. Geol. Yorksh. vol. ii. p. 222, t. 12. f. 25–30.

Rhynchonella pleurodon, Dav. Monogr. Brit. Carb. Brach., Pal. Soc. p. 101, t. 23. f. 1–15, 16–22.

Our *single* specimen seems to be a characteristic *Rhynchonella pleurodon*, according to Phillips, although I know how uncertain it is to refer single specimens to any species; this, however, is another link in the evidence of the wide distribution of forms occurring in the Carboniferous rocks, both European and American. Russia, Belgium, Australia, and America claim this shell, occurring, as it does, almost as profusely at the antipodes as with us in the Carboniferous Limestone. We now record it from Feilden Isthmus, lat. 82° 43′.

DEVONIAN.

It is only through a few fossil Brachiopoda that I venture to determine the presence of the Devonian rocks immediately south of

Cape Joseph Henry and Feilden Isthmus, at Ravine, Dana Bay, head of Porter Bay (82° 42′), and apparently faulted against the Cape-Rawson series. The facies of the few species occurring differs essentially from the Carboniferous, but they are not numerous enough to allow of generalization or correlation; still undoubtedly they are of American affinities. The want of fossil Invertebrata in the Scotch Old Red Sandstone at once removes them from comparison or correlation with that area; only to the North-American types therefore can we compare them, where a magnificent marine fauna exists equivalent to the Devonian of Devonshire, Rhenish Prussia, Belgium, and France, intervening between the summit of the Silurian and the base of the Carboniferous rocks. The typical Devonian rocks of Europe, Britain, and North America are the deep-sea deposits of the Devonian period; whereas the Old Red Sandstones of Britain, and the corresponding Gaspé group of Eastern Canada, may be the shallow-water or near-shore deposits of the same period. I have no means of determining to which section of the Devonian series our few specimens belong; but the *Spiriferæ* would lead me to infer that they were Upper Devonian. There is no evidence of Heer's "Ursa stage" above these, and no plant-remains of any kind have occurred. This is the first notice of the probable existence of a Devonian fauna so far north. Heer's determination of the Ursa-stage flora within the Arctic zone, at Bear Island, and the age of the sandstones of Parry and Melville Islands*, tend to show how widely the Upper Devonian series is distributed, when it embraces the Irish, Rhenish, and St. John's, New Brunswick, floras of a group of rocks below the Carboniferous Limestone, or even the Calciferous series of Scotland. We are able to trace this same group of either Upper Devonian or Lower Carboniferous rocks, which Heer denominated the Ursa stage, over nearly thirty degrees of latitude.

Class BRACHIOPODA.

SPIRIFERA allied to S. PENNATA, D. Owen, Geol. Rep. of Wisconsin, Iowa, and Minnesota, p. 585, t. 3. f. 3, 4, 8; Hall, Geol. of Iowa, vol. i. pt. 2, p. 510, t. 5. f. 1. (Pl. XXIX. fig. 1.)

We possess only the ventral valve of this shell; it is certainly closely allied to Dale Owen's species. Owing to the removal of much of the shell, the number and condition of the ribs on either side of the mesial fold and sinus cannot be satisfactorily determined. I am obliged to depend more upon the figure than the description, owing to its generalities. The aspect of this shell, with a few others from the same locality and horizon, strongly impresses me with their Devonian facies. The presence of wings or extensions on either side of the median sulcus allies it to the *convoluta*-group in the Carboniferous Limestone; indeed many forms of *Spirifera convoluta* closely resemble the shell I have referred to *Spirifera pennata*; nevertheless I cannot refer it to *Spirifera convoluta*. All the forms which

* Heer, "Carb. Flora of Bear Island," Quart. Journ. Geol. Soc. vol. xxviii. pp. 161–169 (1872).

I refer to the Devonian rock very closely resemble Tasmanian species, and certainly have that facies. Dale Owen's specimens were obtained from the Devonian of the Hamilton group, Iowa and Rock Island, Illinois, lat. 41° and 42° N. Our specimens are from Ravine, Dana Bay, lat. 82° 42′, south of Cape Joseph Henry, and below the Carboniferous Limestone of Feilden Isthmus.

Spirifera Aldrichi, Eth. (Pl. XXIX. fig. 2.)

I cannot find any American or British *Spirifera* that will agree with this single specimen, the nearest form I know being *Sp. cultrijugata*, Röm.*, a common species in the Devonian of South Cornwall, but usually found in a distorted and flattened condition.

Sp. char. Shell transversely semicircular, hinge-line as wide as the shell, acute at extremities; dorsal valve slightly convex, no mesial fold or large central rib, seven or eight strong simple ribs on either side of the central pair or on the lateral portions of the valve; ventral valve not seen, a cast of the mould indistinctly shows an intermediate or intercalated slender rib (between the larger ones), extending from the umbonal region to about halfway down the valve. This character is not seen in Römer's species (*Sp. cultrijugata*) or in Davidson's figure; but this last distinguished Brachiopodist states that he has a "specimen from the falls of Ohio (Louisville) with small ribs, and in some places bifurcated." Our specimen is only a cast, so that the intercostal or intercalated rib may be one of many on a more perfect shell. *Spirifera undifera*, Röm., and its var. *undulata*, also much resembles *S. Aldrichi*; but the mesial fold is more pronounced, and the intercostal or tuberculated rib is present at the ventral instead of the dorsal portion of the shell. Concentric ridges are not seen over our cast. I regret we have no better evidence to go upon than our one shell. Something, however, must be done with it. I name this shell after Lieut. Aldrich, to whose labours and researches during the sledge-journey round the northern coast of Grant Land we owe so much intimate knowledge of land and ice. The privation and labour undergone in bringing home such evidence, under such adverse circumstances, deserves to be honourably recorded.

Loc. Ravine, Dana Bay, lat. 82° 42′.

Spirifera, sp., allied to S. granulifera, Hall.

Delthyris granulifera, Hall, Geol. Rep. Fourth District New York, pp. 206, 207, f. 1.

Sp. arcta, Hall, 10th Rep. State Cabinet, p. 161.

Sp. granulifera, Hall, Pal. New York, pt. 4, vol. iv. p. 223, t. 36 & 37.

This species illustrates a series of forms subject to great variation, both as regards general form and details of the ribs and mesial fold. The curvature or incurvation of the beak I cannot determine, none

* Rheinisch. Uebergangsgeb. p. 70, t. 4. f. 1.

Brachiopoda	—— allied to P. punctatus, *Martin*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	*
	—— mesolobus, *Phill.*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	*
	—— fimbriatus, *Sow.*	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	*
	—— costatus, *Sow.*	...	...	...	...	...	...	...	...	...	...	...						

being exposed; in other words, we have only a single valve (dorsal), and this partly imbedded in the matrix. It is as variable a shell as *Sp. disjuncta*, Sow., which has received about twenty different names. Hall describes the shell as having a ventricose dorsal valve and prominent rounded mesial fold, rather prominent beak, and area somewhat large, about twenty simple plications on either side of the sinus (our specimen has not so many, twelve to fourteen). No shell being left, we have no means of knowing whether granulose longitudinal striæ existed (as in Hall's shells) or not, these being seen only on well-preserved specimens. The five varieties named by Hall and his descriptions tend to show the variability of these Spiriferidæ. The Hamilton group in Maryland, Virginia, Pennsylvania, New-York State, Erie and Genesee county yield this shell. Our specimens come from Ravine, Dana Bay, lat. 82° 42′, from beneath the Carboniferous series of Feilden Isthmus.

Orthis?, Chonetes or Streptorhynchus. (Pl. XXIX. fig. 4.)

This one specimen may be either a *Chonetes* or *Streptorhynchus*; the hinge-line being hidden, we have no good characters to aid us in determination.

Loc. Feilden Isthmus, lat. 82° 43′.

Productus, sp., allied to P. costatus or P. mesolobus.

This single specimen is evidently of the same species as those I have referred to as *Productus costatus* from the Carboniferous Limestone of Feilden Isthmus; it is, however, associated with those coarsely costated and broadly winged *Spiriferæ* which characterize the Devonian rocks. From Captain Feilden's notes the beds containing these shells must underlie the Carboniferous series, or be at their very base; and this adds strength to the grouping adopted for their reception between the Upper Silurian and Carboniferous series. No *Productus* appears to be known in the Devonian rocks of Canada, and there are only three or four from the Devonian of North America. *Strophalosia* is its representative genus in the British Devonian rocks of North Devon, &c. The genus *Productus* is essentially Carboniferous *in specific value*; its association with *Spirifera pennata*, *Sp. Aldrichi*, and *Sp. granulifera* is confirmatory of its stratigraphical position.

Loc. South of Feilden Isthmus, lat. 82° 43′.

EXPLANATION OF PLATES XXV.–XXIX.

Plate XXV.

Fig. 1. *Monograptus convolutus*, His., var. *Coppingeri*, Eth., p. 577.
Figs. 2, 3. *Pentamerus Coppingeri*, Eth., p. 594.
Fig. 4. *Strophodonta Feildeni*, Eth., p. 598.
Fig. 5. *Spirifera*, sp., allied to *S. Grimesi*, Hall, p. 628.

Table showing the Geographical Distribution of the Polar Palæozoic Fossils, arranged according to Latitude; also zoologically classified.

		Species.	Washington-Irving Island. Lat. 79° 34′.	Cape Louis Napoleon. Lat. 79° 38′.	Cape Leidy. Lat. 79° 38′.	Dobbin Bay. Lat. 79° 40′.	Cape Hilgard. Lat. 79° 41′.	Gould Bay. Lat. 79° 43′.	Hayes Point. Lat. 79° 42′.	Cape Frazer. Lat. 79° 45′.	Cape John Barrow. Lat. 79° 48′.	Petermann Fjord. Lat. 81°.	Bessels Bay. Lat. 81° 6′.	Offley Island. Lat. 81° 16′.	Cape Tyson. Lat. 81° 20′.	Polaris Bay. Lat. 81° 35′.	Thank-God Harbour. Lat. 81° 40′.	Ravine, Dana Bay. Lat. 81° 40′.	Feilden Peninsula. Lat. 82° 43′.
			Silurian.															Devonian.	Carboniferous.
Carboniferous.	Cœlenterata	Syringopora, sp.																	*
		Lithostrotion junceum, *Flem.*																	*
		Chætetes allied to C. tumidus																	*
	Annelida	Serpulites carbonarius, *M'Coy*																	*
	Polyzoa	Fenestella? arctica, *Salt.*																	*
		——, sp.																	*
		——, sp.																	*
		——, sp.																	*
		Polypora grandis, *Toula*																	*
		—— megastoma, *De Kon.?*																	*
		—— biarmica, *Keys.*																	*
		——, sp.																	*
		Ramipora Hochstetteri, *Toula*																	*
		Phyllopora, sp.																	*
	Brachiopoda	Spiriferina cristata, *Schloth.*																	*
		Spirifera duplicicosta, *Phill.*																	*
		—— allied to S. Grimesi, *Hall*																	*
		—— allied to S. lamellosa, *M'Coy*																	*
		—— ovalis, *Phill.*																	*
		Productus semireticulatus, *Martin*																	*
		—— allied to P. punctatus, *Martin*																	*
		—— mesolobus, *Phill.*																	*
		—— fimbriatus, *Sow.*																	*
		—— costatus, *Sow.*																	*
		—— Weyprechti?, *Toula*																	*
		Streptorhynchus crenistria, *Phill.*																	*
		Rhynchonella pleurodon, *Phill.*																	*
Devonian.	Brachiopoda	Spirifera allied to S. pennata, *D. Owen*																*	
		—— Aldrichi, *Ether.*																*	
		—— allied to S. granulifera, *Hall*																*	
		Productus allied to P. costatus or P. mesolobus																	*
Silurian.	Plantæ	Buthotrephis gracilis, *Hall*						*											
	Protozoa	Stromatopora concentrica, *Goldf.*											*						
		Receptaculites arcticus, *Ether.*		*						*									
		—— occidentalis, *Salt.*		*															
	Cœlenterata	Monograptus convolutus, *His.*															*		
		Favosites gothlandicus, *Fougt*	*			*				*			*	*	*	*			*
		—— alveolaris, *Goldf.*	*																
		——, sp.		*															
		Halysites catenulatus, *Linn.*				*	*			*									
		—— ——, var. Feildeni, *Ether.*					*												
		—— ——, var. Harti, *Ether.*								*									
		Heliolites megastomus, *M'Coy*										*							
		Alveolites, sp.		*						*									
		Syringopora parallela, *Ether.*				*													
		Cyathophyllum articulatum, *Wahl.*				*	*												
		Chonophyllum, sp. allied to magnificum, *Billings*				*													
		Calophyllum phragmoceras, *Salt.*					*												
		Arachnophyllum Richardsoni, *Salt.*					*												
		Favistella reticulata, *Salt.*					*												
		—— Franklini, *Salt.*				*	*												
		Sarcinula organum, *Lam.*					*												
		—— ——, var.					*												
		Zaphrentis, sp.				*							*	*					
		——, sp.											*						
		—— offleyensis, *Ether.*												*					
		——, sp. allied to prolifica, *Billings*				*													
		Strephodes Austini, *Salt.*					*												
		Amplexus Feildeni, *Ether.*												*					
		——, sp.												*					
	Crustacea	Bronteus flabellifer, *Goldf.*											*						
		——, sp. allied to hibernicus?, *Portl.*											*						
		Asaphus tyrannus?, *Murch.*		*															
		Calymene, sp. (? C. senaria, *Conrad*)				*													
		——, sp.							*										
		Encrinurus lævis, *Angelin*				*													
		Proetus?			*														
		Crustacean remains		*															
	Brachiopoda	Pentamerus Coppingeri, *Ether.*												*					
		——, sp.																	*
		Rhynchonella nucula, *Sow.*											*						
		Chonetes striatella, *Dalm.*		*															
		Atrypa phoca, *Salt.*				*							*						
		—— Mansonii, *Salt.*											*						
		—— reticularis, *Linn.*				*	*												
		Strophomena euglypha, *His.*		*			*												
		—— siluriana, *Dav.*			*														
		Meristella tumida, *Dalm.* (? loc.)																	
		Strophodonta Feildeni, *Ether.*					*												
	Gasteropoda	Murchisonia latifasciata, *Ether.*												*					
		——, sp.												*					
		Raphistoma æquale, *Salt.*							*										
		Helicotoma Naresii, *Ether.*												*					
		Holopella							*		*								
		Acroculia haliotis, *Sow.*				*							*						
		Platyceras naticoides, *Ether.*											*						
	Heteropoda	Maclurea magna, *Lesueur*		*			*												
		—— Logani, *Salt.*											*						
		Bellerophon											*						
	Cephalopoda	Orthoceras imbricatum, *Wahl.*				*													
		——, sp.												*					
		—— nummularium, *Sow.*											*						
		Cyrtoceras, sp.												*					

PLATE XXVI.

Fig. 1. *Syringopora parallela*, Eth., p. 583.
Fig. 2. *Zaphrentis offleyensis*, Eth., p. 588; 2 *a*, section showing calice.
Fig. 3. *Amplexus Feildeni*, Eth., p. 589.
Fig. 4. *Amplexus*, sp., p. 589.

PLATE XXVII.

Fig. 1. *Murchisonia latifasciata*, Eth., p. 600.
Fig. 2. *Murchisonia*, sp., p. 601.
Fig. 3. *Helicotoma Naresii*, Eth., p. 602.
Fig. 4. *Platyceras naticoides*, Eth.; 4 *a*, variety, p. 603.

PLATE XXVIII.

Fig. 1. *Halysites catenulatus*, Linn., var. *Feildeni*, Eth., p. 582.
Fig. 2. *Halysites catenulatus*, Linn., var. *Harti*, Eth., p. 583.
Fig. 3. *Chonophyllum*, sp. (allied to *magnificum*, Billings), p. 584.
Fig. 4. *Polypora biarmica*, Keyserl. p. 622.
Fig. 5. *Zaphrentis*, sp., p. 588.

PLATE XXIX.

Fig. 1. *Spirifera*, sp. (allied to *pennata*, D. D. Owen), p. 633.
Fig. 2. *Spirifera Aldrichi*, Eth., p. 634.
Fig. 3. *Spirifera*, sp. (allied to *granulifera*, Hall), p. 634.
Fig. 4. *Streptorhynchus*, sp., p. 635.

DISCUSSION.

The DUKE OF ARGYLL expressed the pleasure he felt at having listened to these most interesting papers, and remarked that, taking into account the enormous difficulties in the way of collecting fossils and rock-specimens under the conditions in which the expedition was placed, no apologies were needed for the smallness of the collection. Indeed he thought that we ought rather to be surprised that so much had been brought. The papers raised questions of the highest interest, but it was impossible to discuss them adequately in the brief time at the command of the meeting; for his own part, he should prefer to wait for their publication.

Mr. CHARLESWORTH commented on the reported absence of Lamellibranchiate Mollusca, and remarked that all negative evidence of this kind required to be received with great caution.

Prof. T. RUPERT JONES said that these papers were founded on the application of modern ideas to great tracts of which but little was known. It was remarkable, considering how small the amount of materials brought back necessarily was, that it should have furnished such exceedingly important evidence in connecting the strata of various countries and in elucidating preexisting difficulties. He thought that we were greatly indebted to the Expedition, although undoubtedly much still remained to be done; and it was to be hoped that future expeditions would clear up many doubtful points and supply much new and desirable information. He remarked that the Vienna 'Transactions' contained a memoir relating to the Austrian expedition, in which, he thought, it was shown that passage-beds existed between the Carboniferous and Permian, in which case we should hardly be justified in drawing between them quite so hard a line as Mr. Etheridge had done.

Sir Leopold M'Clintock said that other expeditions had met with great difficulties in collecting specimens, and that he had himself been obliged to leave behind him a collection of fossils, which was still probably lying as he left it, carefully packed on his sledge. Another collection went to the bottom in the ship; and generally he had been obliged to content himself with bringing the very smallest specimens, in fact such as could be carried in the waistcoat pocket. The same difficulties would affect all Polar expeditions alike, so that there were good excuses for the officers of former expeditions if they did not bring back large collections; and, further, it must be borne in mind that most of them were sent out only for search-purposes, with which the collecting of natural-history specimens was, to a great extent, incompatible.

Dr. Rae said that the coasts he had passed over were unfossiliferous, but that he had been fortunate enough to bring home such geological specimens as he had collected. He inquired whether the officers of the recent expedition had noticed a phenomenon which he had observed at his winter quarters. The tide here rose and fell 8 or 10 feet, and boulders lying even below *low-water mark*, or pebbles from the beach, got frozen early in the winter into the ice formed, and as the mass increased became imbedded in it, until when the thawing of the ice commenced in the spring they made their appearance on the upper surface.

Prof. Ramsay said that it was difficult to discuss papers covering so many subjects. With regard to Mr. Etheridge's suggestion that there had been deep fjords in Silurian times, he stated that he felt doubtful, as all such fjords now in existence are connected with ice-action and associated with boulders, which do not appear to be present in the deposits. He thought, also, that the presence of Brachiopoda could not be taken to prove deep water.

Dr. Gwyn Jeffreys remarked that the living Brachiopoda had a very wide range in depth—some, such as *Terebratulina*, being found down to great depths; whilst others, such as *Rhynchonella*, were shallow-water forms. Some of the fossils seemed to him to show signs of being southern forms. The Chalk had been mistaken for a deep-water formation, which showed how difficult it was to decide on depth by fossils.

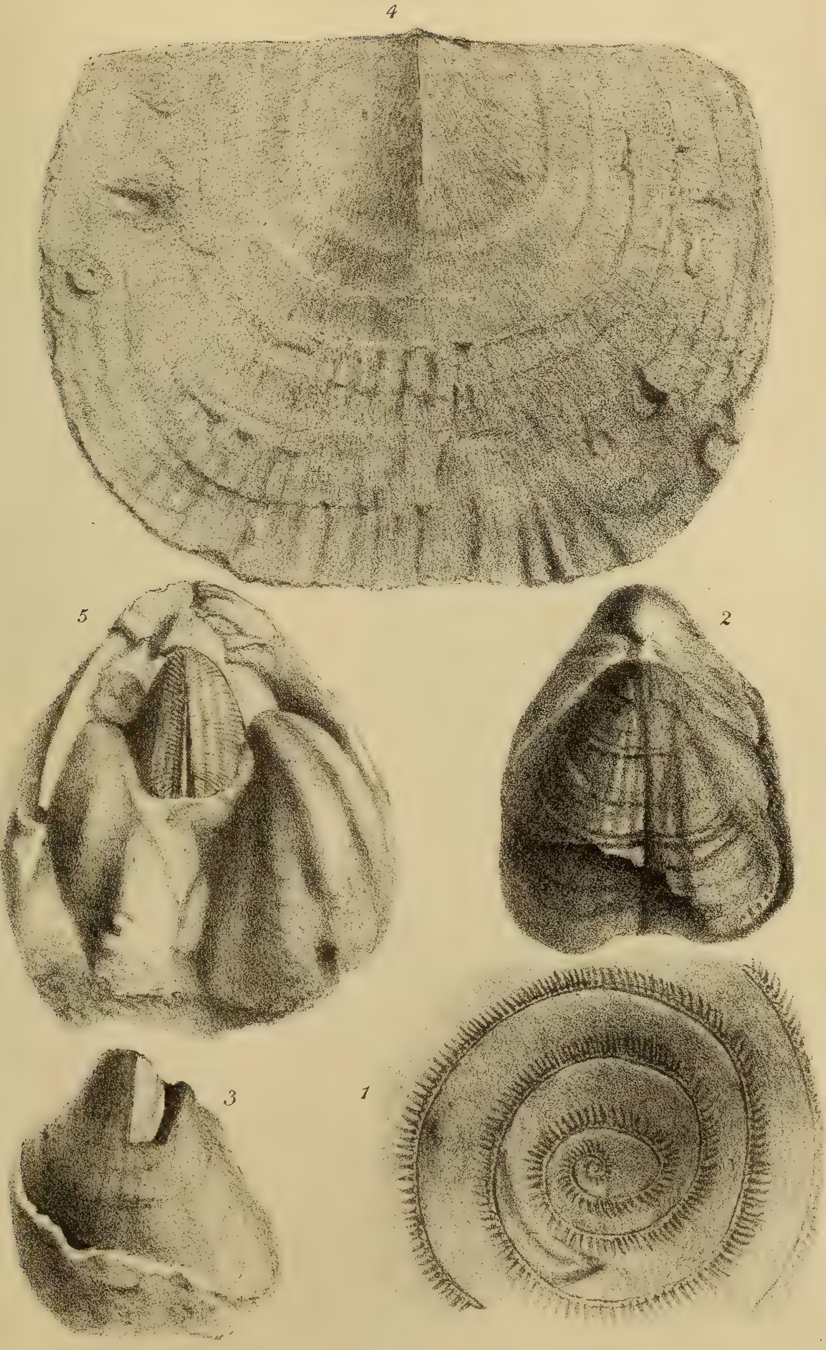
The Duke of Argyll inquired how deep the ice-cap on the mainland of Greenland was, not in the valleys, but on the hills or tablelands, where it was strictly an ice-cap. If it was no more than some 50 feet it was surely inadequate to produce the phenomena attributed to the action of similar sheets of ice.

Rev. J. F. Blake called attention to the way in which certain genera, such as *Bronteus* and *Zaphrentis*, had been said to occur on horizons different from those of which they are usually regarded as characteristic. Hence it was apparently very difficult to decide as to the age of the rocks. On the whole it appeared to him that the existence of the Lower Silurian was proved, but he doubted whether there was sufficient evidence for the Devonian. He thought the deposits so designated were more likely to represent a marine stage of the *Ursa* series. He called the attention of the Society to these fossils as showing the existence of a temperate climate near the pole, proving that the present condition of the polar regions, rather than the Miocene one, was to be regarded as exceptional.

Dr. Henry Woodward complimented Capt. Feilden on the series of fossils that he had collected, and said that the specimens exhibited formed only a part of them. With regard to Sir Leopold M'Clintock's statements, he said that, notwithstanding his having been so unfortunate as to be compelled to leave some behind him, he had nevertheless succeeded in bringing home a valuable collection of fossils, and so also had Sir John Richardson from the Mackenzie River (of Miocene age). With regard to Mr. Blake's remarks, he stated that in England *Bronteus* occurs in the Upper Silurian, so that Mr. Etheridge might fairly attribute to the beds containing that genus an Upper Silurian age. He was unable to offer any opinion as to the other supposed Crustacean remains, as they were excessively indistinct.

Mr. Bauerman stated that the gneiss seemed to him to correspond with that of the upper part of the Lower Laurentian, the true upper series, so rich in Labrador, being apparently wholly absent in these Arctic regions. The shales provisionally called Huronian certainly corresponded with some occurring in Canada; but they presented no signs of the hæmatite there found, nor of the galena characteristic of the Lower Silurian of Hudson's Bay. Hence, though there was a general similarity to the Hudson's Bay rocks, there were, nevertheless, some important differences.

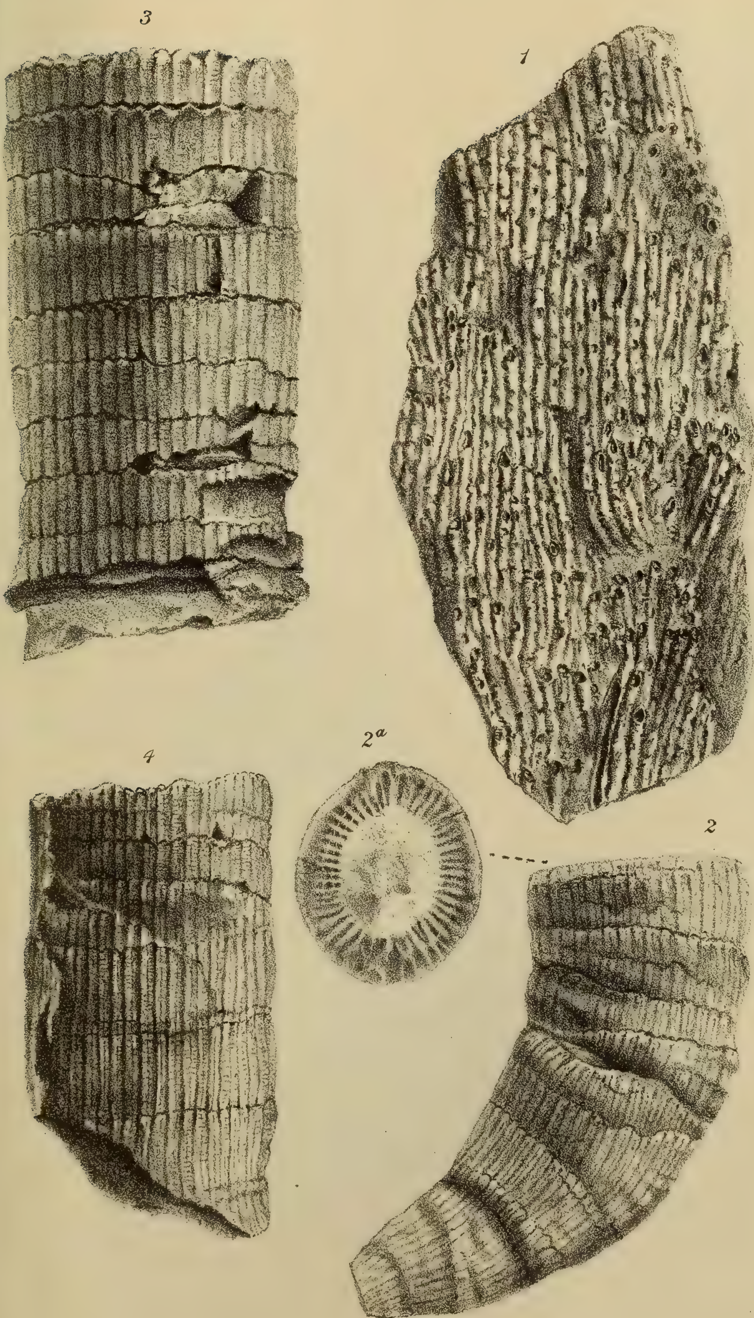
Mr. Belt desired to draw attention to a hiatus in the geological record contained in the rocks of the Arctic regions. The authors had noticed the absence of Permian or Triassic deposits; but he did not refer to that, but to a much more remarkable break, namely the presumed absence of strata of Eocene age. In Central Europe in Eocene times tropical plants abounded. Later on the tropical forms disappeared and were replaced by the Miocene flora, containing genera and species that betoken a more temperate climate. It seemed to him, therefore, most likely that the supposed Miocene plants really lived near and around the pole in Eocene times, and migrated southward in the Miocene epoch, when the climate of the Arctic regions became too cold for them. The presence of Miocene species in the Arctic deposits no more proved that they lived there in Miocene times than that of recent species, such as *Pinus abies*, *P. montana*, and *Taxodium distichum*, showed that they lived there in recent times. The absence of an Eocene flora could not be explained by supposing that the Arctic area was then submerged; for no Eocene marine strata had been brought up by the great post-Tertiary elevations that had taken place. He would be glad to learn if the authors



G. Sharman lith.

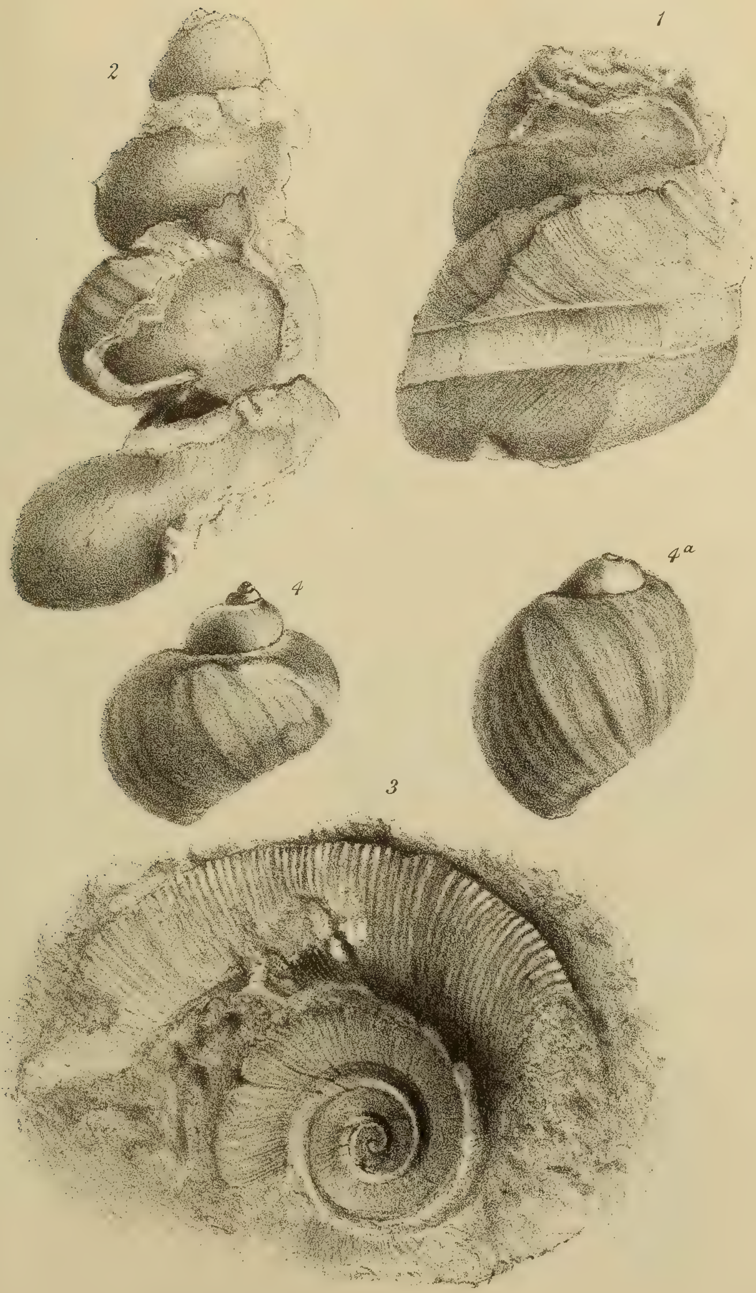
Hanhart imp.

ARCTIC PALÆOZOIC FOSSILS.



L. Sharman lith. Hanhart imp.

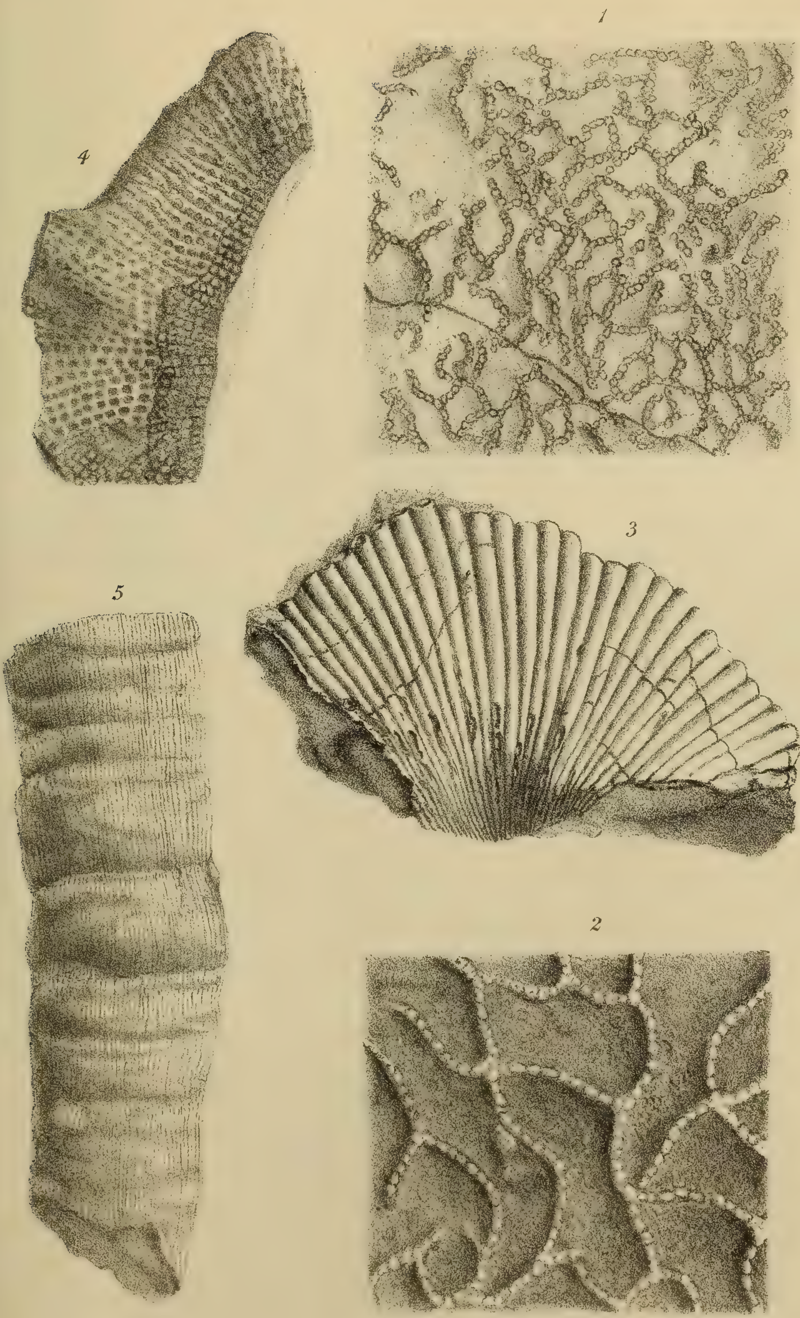
ARCTIC PALÆOZOIC FOSSILS.



G. Sharman lith.

Hanhart imp.

ARCTIC PALÆOZOIC FOSSILS.



G. Sharman lith.

Hanhart imp.

ARCTIC PALÆOZOIC FOSSILS.

G. Sharman lith.

Hanhart imp

ARCTIC PALÆOZOIC FOSSILS.

could give any more probable explanation of the supposed absence of Eocene strata than that he had suggested.

Mr. J. S. Gardner did not believe the beds were Miocene, and called attention to the fact that many Miocene plants are common to the Eocene, as was shown by the American beds.

Capt. Feilden, in reply to the Duke of Argyll, said that they had noticed the Petermann ice-cap because it was so different from the ordinary one, and had been fully described in the Blue Book.

Mr. De Rance, in reply to Mr. Belt, said that the Austrian geologists had identified Lias and, he believed, Trias in Spitzbergen. He thought that the presence of an Eocene flora followed by a Miocene one was rather opposed to Mr. Belt's idea of the real Eocene age of the supposed Miocenes of the Polar regions.

Mr. Etheridge said that he had been obliged to use negative evidence because it was the best there was. He could not agree with Prof. Ramsay as to the absence of fjords. At present there are plenty of Lamellibranchs near the pole, but now there are plenty of shores on which they can live. They were not here in these early times at any rate; though many fossils had been brought, no Lamellibranchs had been found among them. He would take into consideration Prof. Jones's remarks. He thought he was justified in referring the rocks with *Bronteus flabellifer* to the Silurian, though in Britain it is a Devonian form.

37. *On the* Great Flat Lode *south of* Redruth *and* Camborne, *and on some other* Tin-deposits *formed by the* Alteration *of* Granite. By C. Le Neve Foster, Esq., B.A., D.Sc., F.G.S. (Read January 9, 1878.)

[Plate XXX.]

Few persons who have visited West Cornwall can have failed to notice the marked hill known as Carn Brea, about a mile S.W. of Redruth. This hill forms part of a mass of granite about four miles long, in a direction E. 30° N., generally about five furlongs wide, but terminating both east and west in a long narrow tongue. The granite is surrounded on all sides by the so-called killas or clay-slate. To the north of the hill are numerous famous mines, such as Dolcoath, Cook's Kitchen, Tincroft, and Carn Brea; and to the south, again, mining operations have been carried on to a considerable extent. I propose to describe some of these latter workings, which possibly form part of one great mineral vein stretching for more than three miles from Perseverance Mine on the east to South Tolcarne on the west.

The accompanying plan and section (Pl. XXX.), which have kindly been compiled for me from the originals by Mr. Thomas B. Provis, Assoc. Inst.C.E., show the situation of the workings; for the sake of clearness levels on other lodes have been omitted. From a cursory inspection of the plan it would appear doubtful whether all the workings belong to one and the same lode; the West Wheal Frances drivages, for instance, are not in a line with those at similar levels to the E. and W. This shift of a portion of the lode to the south may have been caused by north and south faults (*cross courses*), several of which are known to exist; however, the continuity or non-continuity of these deposits is not a question which affects the purpose of my paper, the main object of which is to describe the occurrence of the tin-ore and point out how the mineral repositories in question differ from those which are included in the ordinary definition of a *lode* or mineral vein.

I propose to treat the subject under the following heads:—

I. Description of the lode as seen at the various mines.
II. Its probable mode of origin.
III. Alteration of granite in other districts.
IV. The definition of the term *lode* or *mineral vein*.
V. Statistics of the output of tin-ore from the Great Flat Lode.

I. Description of the Lode.

Wheal Uny lies a little to the S.E. of Redruth Church, and is entirely dependent on the Great Flat Lode. In the eastern part of the mine, the strike is about 22° N. of W., but to the W. the vein turns round south and strikes W. 37° S., or even in some places for a short distance S.W.; it dips about 46° south, and is consequently very much flatter than veins usually are in Cornwall, 70° being a commonly accepted average dip. It has been wrought for a distance of more than 300 fathoms along the strike and 160 fathoms in depth.

One peculiarity of the lode at Wheal Uny is that it lies at the very junction of the granite and the killas; and if looked at by itself it might be considered an example of "contact deposit." However, as the workings to the west show us a somewhat similar lode in clean granite, it is evidently not necessarily connected with any phenomena due to contact of dissimilar rocks.

Fig. 1.—*Section showing the Lode at Wheal Uny at the 130-fathoms Level.*

A. "Leader." B. Lode. D. "Greyback."
E. Capel. F. Killas. G. Granite.

The section (fig. 1) shows the appearance of the lode at the 130-fathoms level. A is the so-called *leader*. In one part it is 18 inches wide, consisting of a mass of fragments of more or less altered killas (*capel*) with some tin-oxide, and it soon dwindles down to a mere *flucan*, or vein of clay, with a little quartz, only 2 inches wide. The sides (*walls*) are very smooth, presenting numerous slickensides; in fact this leader has all the appearance of being a mere crack, filled in the main mechanically by fragments of the sides reduced in places to a clay by the attrition of the *walls*.

B is the lode, a very fine-grained or compact bluish-grey schorl-rock, with little spots or strings and veins of quartz, cassiterite, chlorite, and iron-pyrites.

D is a rock locally known as "greyback," or "black granite," but not separated from B by any distinct line. It is a schorl-rock with large grains of quartz in a compact black matrix.

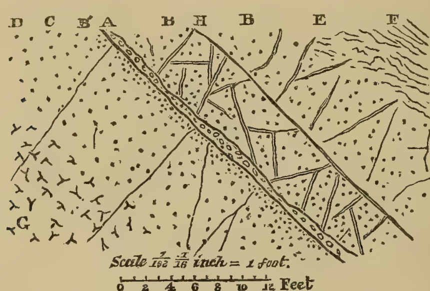
E is hard compact *capel* or schorl-rock.

The killas, F, to the south, and the granite, G, to the north, are rarely seen during the workings on the lode; but their presence is well ascertained by crosscuts and shafts in these enclosing rocks or *country*. The crosscuts have further proved that there is no *wall*, or definite plane of division, between the *greyback* and the granite, any more than there is between the *greyback* and the lode; nor is there any straight line of demarcation between the killas and the *capel*.

There may be a much greater quantity of *capel* above the lode than is shown in my sketch; in fact the crosscut south at the 80-fathoms level shows that it extends for many fathoms, whilst the killas that is eventually met with is converted into mica-schist.

As may be naturally supposed, the lode varies a great deal in character. Sometimes the tin-bearing rock, or lode, is above instead of being below the leader; thus, in some stopes above the 110-fathoms level, I saw the following section (fig. 2):—

Fig. 2.—*Section at Wheal Uny, above the* 110-*fathoms Level.*



A. *Leader*, 2 to 10 inches wide, a breccia of fragments of chloritic slate cemented by iron-pyrites and quartz.

B B. *Lode*, a very fine-grained or compact stanniferous schorl-rock, with strings and spots of quartz and cassiterite, and numerous veins of quartz enclosing fragments of schorl-rock cemented by iron-pyrites. It is traversed by a clay-vein (*flucan*) H, containing a little quartz and iron-pyrites.

B'. *Lode*, compact schorl-rock, with spots and little veins of quartz and tinstone, 4 inches thick, under the leader.

C. *Capel*, compact schorl-rock, with spots and veins of quartz, containing very little tin, 2 feet thick.

D. *Black granite*, or *greyback*, a schorl-rock with large grains of quartz in a compact black matrix, probably about 6 feet thick.

E. *Capel.* There is a difference between the *capels* C and E; the latter shows the component minerals arranged in layers, which are signs of original stratification; the former does not. F. Killas.

G. *Granite.* Neither of these is actually seen in the section underground.

On looking at the longitudinal section of Wheal Uny it does not seem possible to make out any dip of the bunches of tin-ore; in fact I am informed that no part of the lode is absolutely barren, the rock near the leader will always contain at least ½ per cent. tin-ore (*black tin*).

Where the granite protrudes into the killas the lode may leave the junction and have granite or altered granite on both sides.

At *South Carn Brea* mine, west of Wheal Uny, the same lode was followed down for a depth of 175 fathoms, mainly between the granite and the killas, with the same general features. There was this difference, however, the narrow "leader" became a copper-lode 2 to 4 feet wide, thus :—

Fig. 3.—*Section of Lode at South Carn Brea.*

A. Copper-lode. B, C. More or less stanniferous schorl-rock, *i. e. lode* and *capel.* E. *Capel* (schorl-rock derived from killas). F. Killas. G. Granite.

This mine has been therefore worked both for tin and copper. The outcrop of the Great Flat Lode may be seen a little to the south of the castle on Carn Brea.

The course of the lode was generally about E. 33° N., though it made a bend in one place and had a strike E. 15° N.

The dip is about 35°.

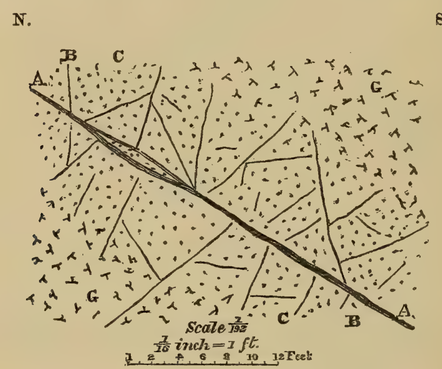
West Wheal Basset.—This mine was originally started to work a copper-lode dipping north ; but eventually the Great Flat Lode was intersected, and it is to this vein that the mine is now indebted for the greater part of its produce. The lode is now entirely in granite, and the accompanying section (fig. 4) of the workings above the 104-fathoms level will explain its character.

Often you may have nothing but non-stanniferous rock (*capel*) below the leader and lode above it ; and very frequently the leader is reduced to a mere ferruginous joint. In one part of the mine, viz. at the 140-fathoms level, the lode and capel are 40 or 50 feet wide altogether, and the whole of the stuff is more or less tin-bearing.

South Wheal Frances.—The Great Flat Lode dips into this mine from West Basset, and was first intersected at the 185-fathoms level ; it is now known also at the 205. The workings at present are not extensive, though decidedly productive ; for the rock is yielding $2\frac{2}{3}$ per cent. of tin ore (60 lbs. to the ton of stuff). The average dip is 32°, and the course, as far as at present determined, is E. 41° N. A cross section through West Basset and South Wheal Frances, prepared by Capt. A. James, the manager of the latter mine, shows how the lode is faulted by three other lodes underlying north.

West Wheal Frances.—I have already pointed out that if the large tin-lode of this mine forms a part of the Great Flat Lode, it must have been considerably shifted out of its proper line by faults. The lode in many places is extremely like that of West Basset; but very often the leader becomes a quartz-vein 2 or more feet wide, and generally poor in tin; this is known as the *cab*. The stanniferous rock is usually under the leader or the cab. The dip of the lode varies from 37° to 50° in the short distance of 80 fathoms along the strike.

Fig. 4.—*Section at West Wheal Basset, above the* 104-*fathoms Level.*



A is the *leader*, a red ferruginous clay-vein with fragments of capel 2 to 3 inches thick.

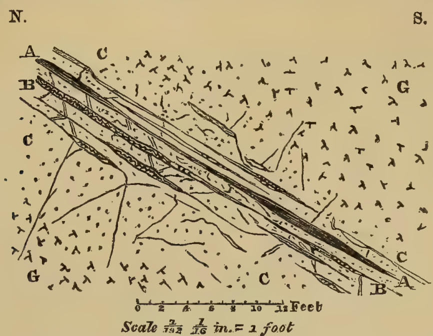
B C, *lode* and *capel*, *i.e.* stanniferous and non- or slightly stanniferous schorl-rock, 9 feet thick above the leader and 6 feet thick below: there is no *wall* between the lode and the capel, nor between the capel and the granite, G G. The stanniferous part has usually a greyish-blue colour and is a compact rock with veins and spots of quartz and cassiterite. The schorl-rock with large grains of quartz in a compact black matrix is invariably unproductive.

South Condurrow.—Here, again, the Great Flat Lode is entirely in granite, though the thickness of that rock on the hanging wall in the upper part of the mine must be small. The general features of the lode are very much the same as in West Basset; you have, in fact, a narrow leader with lode and capel above and below it. The tin-bearing part averages 5 or 6 feet wide, and the lode and capel together will quite make up 12 ft. However, the capel is often very much thicker, especially under the leader, and may reach even 20 feet.

The average bearing in South Condurrow is about E. 34° N., the dip 30° S.

The stopes above the 83-fathoms level have the following appearance (fig. 5) :—

Fig. 5.—*Section at South Condurrow, above the 83-fathoms Level.*



A is the leader, a clay vein with much quartz, red oxide of iron, and some fragments of capel.

B is the tin-bearing rock or lode, about 5 feet thick, a mass of compact stanniferous schorl-rock, black and slaty blue in colour, traversed by a quantity of quartz-veins of all sizes up to 2 or 3 inches in width ; there are numerous little cross veins also, besides vertical joints filled with iron-pyrites.

C is capel or compact schorl-rock, with spots and veins of quartz ; it is from 2 to 20 feet thick under the lode, averaging perhaps 7 or 8 feet ; the capel above the lode is much veined with quartz and contains little or no tin ; it is useful in forming a strong roof.

In the stopes above the 93-fathoms level the tin-bearing part is above the leader (fig. 6). Twelve feet of the rock contain a sufficient amount of tin to make it worth extracting. The lode, as before, is a schorl-rock traversed by innumerable quartz-veins, a great many of which dip N. at a high angle.

Fig. 6.—*Section at South Condurrow, above the 93-fathoms level.*

A. Leader. B. Lode. C. Capel. G. Granite.

In many places the Great Flat Lode contains a good deal of chlorite, some iron-pyrites, and kaolin. Occasionaly kaolin fills up *vughs* or cavities in the quartz-veins.

There is no wall or plane of separation between the lode and the capel, nor between the capel and the granite; the passage is gradual. The granite near the capel is frequently soft, from the orthoclase being wholly or partly kaolinized.

Wheal Grenville.—On account of its dip, the Great Flat Lode leaves South Condurrow at the 93-fathoms level and enters Wheal Grenville, where it has been worked on between the 130 and 160 fathoms levels. Comparatively little work has yet been done here; the course of the lode in the present workings is from 27° to 32° N. of E., and the dip about 30° S. The *leader* varies from a mere joint to 2 feet in thickness, and on each side you have a "capelly" lode. Of this, about 2 feet are taken on each side with 1·6 per cent. (36 lbs. per ton of stuff) tin-ore, whilst capels are left standing 1 to 8 feet thick, containing $\frac{1}{2}$ to 1 per cent. tin-ore, which is rock that cannot be worked with profit at present prices.

I may be fairly asked to bring forward proofs that the lode and capel are really schorl-rock; for they differ very decidedly from a typical granular schorl-rock, such as that of Roche, for instance. I was first led to infer the presence of schorl from finding evidence of much boron while examining the lode-rock by the blowpipe ('Mineralogical Magazine,' vol. i. 1877, p. 75); and subsequent tests revealed the existence of fluorine, silicon, aluminium, potassium, and iron, all of which are component elements of tourmaline.

I then called the microscope to my aid. Thanks to the kindness of Mr. J. H. Collins, who readily afforded me every assistance, I have been able to examine some sections of lode and capel prepared for me by Mr. J. B. Jordan. When magnified 300 diameters the capel is seen to consist of a felted mass of minute crystals imbedded in a basis of quartz. In places you observe spots and patches where the quartz predominates; some of these spots are oval and rounded, others angular, and a few that are hexagonal in section naturally suggest the former presence of felspar. Mr. Frank Rutley, who examined several slides for me, agrees with me in this opinion.

The rock forming the lode presents a similar matted mass of fine needles in a ground-mass of quartz, with granules of cassiterite scattered through it or arranged in little strings and veins. The needle-like crystals are very like some larger ones in specimens of undoubted schorl-rock in Mr. Collins's possession. The microscopical evidence is in favour of the opinion forced on me by the blowpipe reactions, which is thoroughly in accordance with the views so ably brought forward thirty-six years ago by Prof. Daubrée with regard to the minerals associated with tin-ore*.

* "Mémoire sur le gisement, la constitution, et l'origine des amas de minerai d'étain." Annales des Mines, 3me série, tome xx. 1841, p. 65.

II. Probable Mode of Origin of the Great Flat Lode.

We have now to consider the mode of origin of these deposits of tin.

Their distinctive features are:—

1. The invariable presence of a small leader, generally only a few inches wide, apparently occupying the space due to the shifting of the two sides of a comparatively flattish fissure, and filled partly mechanically, partly chemically.

2. A lode or mass of stanniferous schorl-rock, containing 1 to 3 per cent. of cassiterite, from 4 to 15 feet in width, either above, below, or on both sides of the leader. The tin is distributed in little grains in the rock or in strings or minute veins. I believe that the fact of the lodes themselves consisting of *schorl-rock* is a point which has never before been made known.

3. Schorl-rock, poor in tin ore (locally called *capel*, *greyback*, *black granite*), separating the lode from the granite, and schorl-rock with its constituent minerals arranged in layers, also called *capel*, separating the lode from the killas.

4. Gradual passage of the schorl-rock (*capel*) into lode on one side and into granite or killas on the other; in other words, absence of any *wall* between the capel and the lode, or between the capel and the enclosing rocks.

All these facts point, in my mind, to the idea that the lode and capel are merely altered rocks, the fissure now occupied by the leader having served to bring up vapours or solutions capable of entirely changing the rocks on both sides of it. It is very difficult, I admit, to conceive that this compact blue stanniferous schorl-rock could once have been granite; but I may further mention that both at South Condurrow and Wheal Grenville I have found cavities as big as a pea which seem to agree in form with crystals of orthoclase; and the microscopical examination already referred to affords confirmatory evidence on this point.

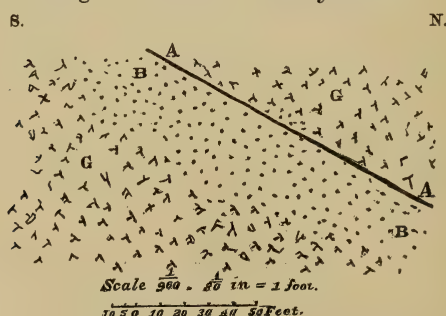
III. Alteration of Granite in other Districts.

That granite can be altered into schorl-rock is a fact that can scarcely be questioned. Every china-clay pit affords us evidence of the fact. You constantly find little veins of quartz, or quartz and tin-ore, bounded on each side by granular schorl-rock, which is followed by granite more or less decomposed. I have specimens in my possession of a passage-rock showing pseudomorphs of gilbertite after orthoclase enclosed in schorl and quartz. The sharp walls of the quartz-veins on the sides of the original fissures and the absence of such walls between the granite and the schorl-rock is what would be expected if the altering solutions gradually soaked in from the sides. Sometimes the schorl-rock itself bears plain marks of its origin, as it contains numerous pseudomorphs of quartz after orthoclase. This is nowhere better seen than in some rocks occurring on the granite near Penstruthal mine south of Redruth. The pseudomorphs are more than an inch long by ¼ inch wide, and are imbedded in a mass of schorl with a little quartz. Killas is also often seen altered into a schorl-rock; but here the two minerals are disposed in layers; sometimes it is schistose (tourmaline schist); at other times compact (*capel*). ("On some Tin Lodes in the St. Agnes District," by C. Le Neve Foster, Trans. Roy. Geol. Soc. Cornwall, vol. ix. part. iii. 1877.)

It must not be supposed that schorl-rock is the only form of altered granite. The conversion of granite into "Greisen" is not uncommon; and Prof. von Cotta * has given ample proof that the fine-grained dark-coloured *Zwittergestein* has also been derived from the same rock. However, without going out of Cornwall, it is easy to find additional instances of the curious changes which granite may undergo. In the parish of Wendron particularly there are some remarkable tin-deposits which deserve special mention on this account. I have already described East Wheal Lovell †, and I will now briefly explain the principal features of the deposits at three other mines known as Balmynheer, The Lovell, and South Wendron.

Balmynheer mine lies about 2¼ miles N.E. by N. from Wendron Church, and is remarkable for presenting a large irregular mass of stanniferous rock. The mode of occurrence will be easily understood by reference to the accompanying section (fig. 7).

Fig. 7.—*Section at Balmynheer.*



AA. Slide. BB. Stanniferous rock. GG. Granite.

GG is ordinary granite. BB is the tin-bearing rock, which occurs in the form of a mass from 30 to 50 feet in thickness, dipping N. at an angle of about 30°, following, in fact, the *slide* AA. This slide is merely a vein of white clay with a little quartz and mica, and is about 6 inches thick. Its course is about E. 32° N. (true), and the dip N. The tin-rock is a mixture of quartz, chlorite, gilbertite, iron-

* Festschrift zum hundertjährigen Jubiläum der königl. sächs. Bergakademie zu Freiberg, p. 156. Dresden: 1866.

† Trans. Roy. Geol. Soc. Cornwall, vol. ix. part ii. p. 167.

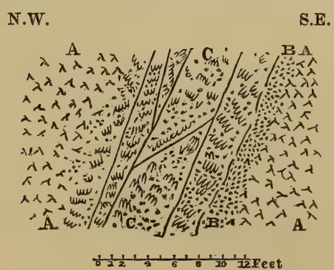
pyrites, zinc-blende, tin-ore, and occasionally a little wolfram. There are a few irregular strings of quartz running through the mass. Much of the rock is full of little cavities; and when this honeycombed structure is apparent, the stone is sure to be rich in tin. Between the tin-deposit and the underlying granite there is no regular plane of separation; on the contrary, there is a gradual passage—the rock becomes less cellular, felspar crystals appear spotted with chlorite, and finally you come to clean granite. Occasionally there is a little tin-rock above the slide, or the granite may contain iron-pyrites, the crystals of which, both here and in the tin-bearing rock below, are often cubes of $\frac{1}{4}$ in. to $\frac{1}{2}$ in. on the side.

The mass of stanniferous rock is known to extend for 36 fathoms along the strike; but it has not been explored further east and west, nor has the depth to which it reaches been ascertained. The lowest workings have been some 30 fathoms from the surface; 2200 tons of tin-stuff were stamped in 1876, and yielded on an average, I am informed, rather more than 1 per cent. of tin-ore (*black tin*).

The Lovell mine, which lies $1\frac{3}{4}$ mile E. by S. from Wendron church, furnishes an example of a still more curious deposit. At this mine there are two so-called *lodes* or veins; the north lode strikes from 37° to 45° N. of E. (true), and dips N.W. at an angle of about 70°; the south lode runs about E. 48° N., and dips N.W. about 60°; the consequence is that the two lodes unite, both going eastward and in depth.

Let me now describe the south lode, which is the more important of the two; and I cannot do better than take the section as I saw it in the 30-fathoms level (fig. 8).

Fig. 8.—*Section at the Lovell Mine, in the 30-fathoms level.*



Scale $\frac{1}{192}$. $\frac{1}{16}$ inch = 1 foot.

AA. Granite. BB. "Cab." CC. Lode.

A A is ordinary granite. B B is the so-called *cab*, which is composed of quartz, mica, gilbertite, chlorite, iron-pyrites, copper-pyrites, and a little schorl. It is usually from 6 to 12 inches thick; and it is sometimes found on both sides of the lode. C C is the lode itself, a compact dark-coloured mixture of quartz, gilbertite, mica, zinc-blende, chlorite, iron-pyrites, and a little copper-pyrites, fluor, and tin-stone. Of this last mineral, the rock contains $2\frac{1}{2}$ per cent. The most remarkable point with regard to this lode is the occurrence of numerous pseudomorphs of quartz after orthoclase, many an inch long by $\frac{1}{4}$ inch wide; and they show out very plainly in the dark ground formed by blende and chlorite. Some of the pseudomorphs contain small grains of cassiterite.

Fig. 9. —*Plan of Lode at the Lovell Mine.*

A. Granite. B. "Cab." C D. Main joint. E F. Joint

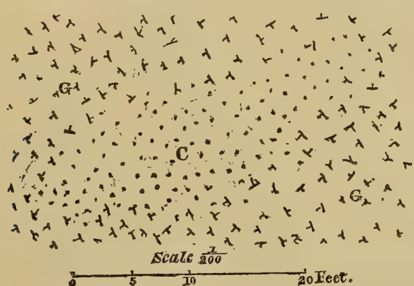
The lode is traversed by numerous joints, which are mere planes of division in the rock; the principal ones dip and strike at the same angle as the lode itself. When, however, a joint diverges, it carries "lody stuff" with it. Thus if a joint, E F, goes off from the main joint, C D (as shown in plan, fig. 9), a little tin-stuff will be found following it for a short distance into the granite.

The north lode is much lighter in colour than the south lode, owing to the absence of blende, and is a mixture of quartz, mica, gilbertite, a little iron-pyrites in cubic crystals, tourmaline, and tin-stone. It is from 10 to 15 feet wide.

It must not be supposed, however, that these so-called lodes or masses of tin-bearing rock run continuously from one end of the mine to the other. Unfortunately they only occur in bunches here and there; and when these gradually come to an end on all sides, the lode becomes a mere joint in the clean granite.

South-Wendron mine, which adjoins The Lovell on the S.E., is worked upon a *pipe* of tin-bearing rock of a somewhat remarkable character (fig. 10). The easiest way of giving an idea of it is to describe it as a very irregular cylindroid of stanniferous rock, merging gradually on all sides into granite, with its axis dipping at an angle of 49° from the horizon in a direction N. 25° W. (true). The longer axis of the oval section of the *pipe* varies from 20 to 60 feet in length, whilst the shorter is about 10 feet. The mass consists of quartz, mica, gilbertite, a little iron-pyrites, and tinstone, and is traversed by a few irregular joints: the stuff is usually cavernous or honeycombed, and in the little cavities fine acicular crystals of tourmaline may often be detected. The southern part of the *pipe* is sometimes very granitic in appearance, and consists of pink orthoclase crystals imbedded in a mass of quartz, chlorite, mica, iron-pyrites, a little copper-pyrites, fluor, and tin-ore. I have one specimen which is a true stanniferous granite; for save a small portion of iron-pyrites and tourmaline, it is made up entirely of tin-stone, orthoclase, quartz, and mica.

Fig. 10.—*Plan of the Deposit at South-Wendron Mine.*



G G. Granite. C. Tin-bearing rock.

The workings extend to a depth of 46 fathoms from the surface, and consist merely of a shaft and a few very short levels or lateral excavations.

The characteristics of these three deposits may be summed up in a very few words; they are masses of stanniferous rock passing gradually into the surrounding granite. The fact of this passage and the presence of the pseudomorphs justify us in concluding that the so-called lode at the Lovell mine was once granite; and if this is admitted, we can have no hesitation in affirming that the Balmynheer and South-Wendron deposits were formed by the alteration of the same rock.

IV. Definition of the Term Lode or Mineral Vein.

The terms lode or mineral vein, commonly regarded as synonymous, are usually taken to mean the mineral contents of a fissure. Thus Mr. Carne says *:—" By a *true vein* I understand the *mineral contents of a vertical or inclined fissure, nearly straight, and of indefinite length and depth.*" In Prof. von Cotta's ' Erzlagerstättenlehre ' (p. 102) we find the definition " Erzgänge sind Spaltenausfüllungen welche Erze enthalten ;" and similar explanations of the term mineral vein are constantly met with.

* Trans. Roy. Geol. Soc. Cornwall, vol. ii. p. 51.

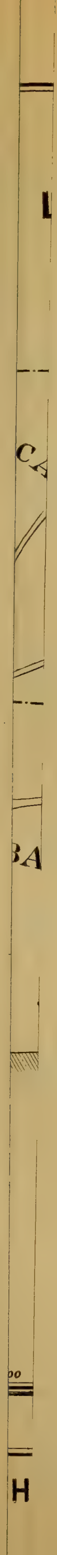
I have endeavoured to show in paragraph II. that the Great Flat Lode is, in the main, a band of altered rock. Much of the veinstone extracted from some of the largest Cornish mines, such as Dolcoath, Cook's Kitchen, Tincroft, Carn Brea, and Phœnix, for instance, closely resembles the contents of the Great Flat Lode, and was probably formed in a similar manner; indeed I question very much whether at least half the tin-ore of the county is not obtained from tabular masses of stanniferous altered granite. If, then, many of the most important lodes of such classic ground as Cornwall do not satisfy the common definition, one of two things ought to be done: either the miner should give up the term lode for these repositories, or else the meaning attached to the word by geologists should be extended. I need hardly say that the first alternative is not likely to be adopted; nor do I think it is one to be recommended; for I believe that one and the same fissure traversing killas and granite may produce the two kinds of lodes. In the non-homogeneous killas the fissure would be more or less jagged, and a shift of the strata would produce open spaces; whereas the same rent passing through the underlying granite of uniform texture would be much straighter, and a shift would cause much smaller openings. The upper part of the lode, resulting from the filling up of the open crack, would satisfy the ordinary definition; whereas the lower part would not, if it merely consisted of altered rock on the sides of the narrow fissure. I should propose, therefore, that the term lode or mineral vein should include not only the contents of fissures, but also such tabular masses of metalliferous rock as those I have been describing near Redruth and Camborne. If, however, this course should be thought on the whole undesirable, the geologist and miner must agree to differ in their language, and some of the *lodes* of the latter will have to be designated as *tabular stockworks* by men of science.

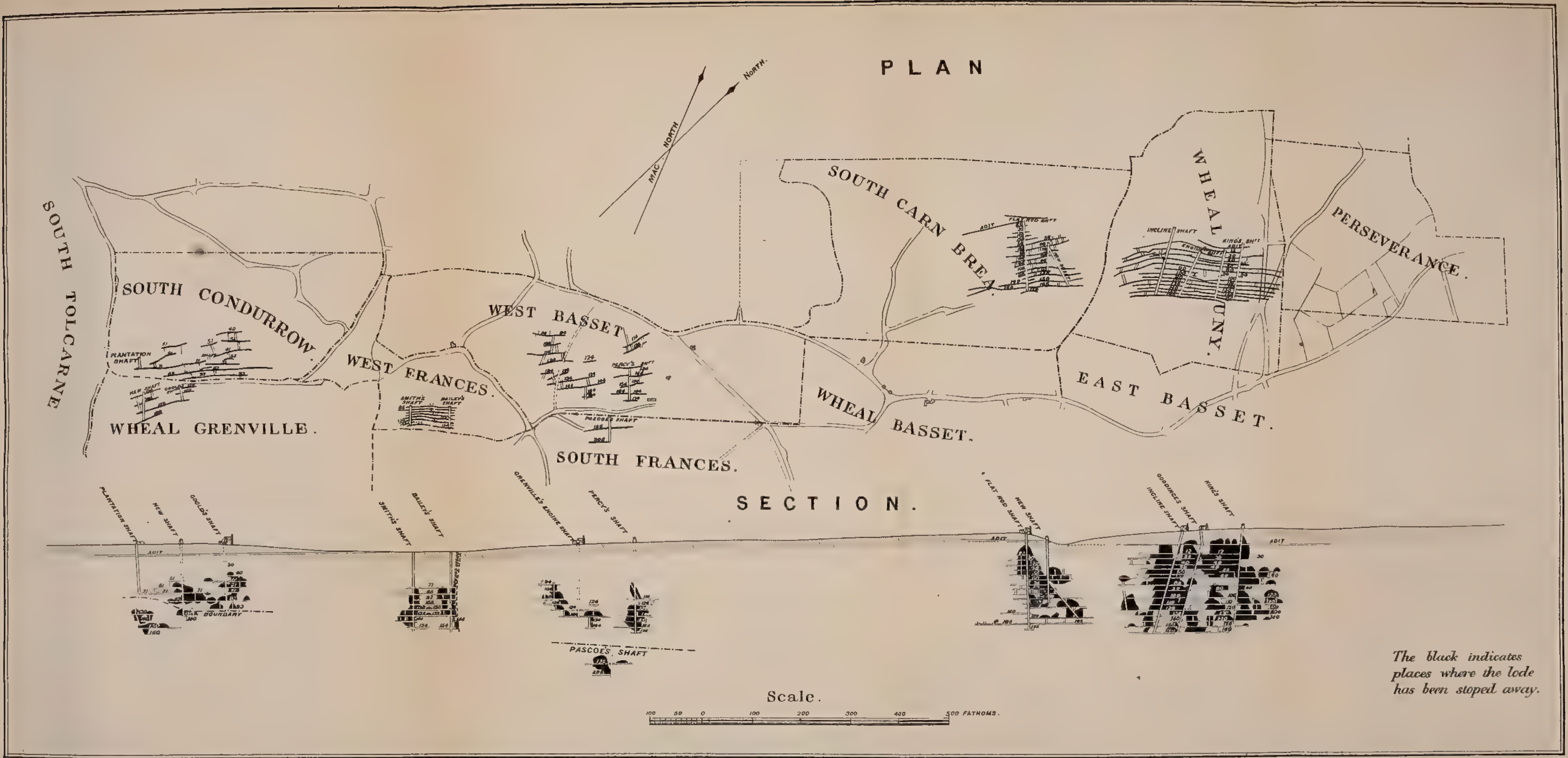
V. Statistics of the Output of Tin-ore from the Great Flat Lode.

I must now call attention to the value of the Great Flat Lode as shown by the following figures:—

		Tinstuff. tons.	Clean tin-ore. tons.
Wheal Uny	in 1876 produced	17,702	349
South Carn Brea	" "	2,040	30
West Basset	" "	29,144	618
West Wheal Frances .	" "	6,652	123
South Condurrow ..	" "	19,414	588
Wheal Grenville	" "	8,500	138
Totals.................		83,452	1846

The six mines, Wheal Uny, South Carn Brea, West Basset, West





PLAN & SECTION OF TIN MINES ON THE GREAT FLAT LODE.

Wheal Frances, South Condurrow, and Wheal Grenville produced in 1876 83,452 tons of tin-stuff, which yielded 1846 tons of clean tin-ore, or at the average rate of about $2\frac{1}{4}$ per cent. In fact the Great Flat Lode alone yielded more than one eighth of the total quantity of tin-ore obtained in Cornwall.

In conclusion, I desire most heartily to thank the agents of the various mines I have described for their readiness to afford me all the information in their power, and for the permission to publish this brief account of some of their workings.*

EXPLANATION OF PLATE XXX.

Plan and Sections of Workings on the Great Flat Lode south of Redruth and Camborne.

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* For the Discussion on this paper see p. 658.

38. *On some* Tin Stockworks *in* Cornwall. By C. Le Neve Foster, Esq., B.A., D.Sc., F.G.S. (Read January 9, 1878.)

The name *Stockwork* is usually applied to large masses of rock impregnated with metallic ores or intersected by a number of mineral veins at short distances apart, sometimes crossing one another in all directions. Not having any word of our own, we have adopted the term Stockwork from the German *Stockwerk*. This expression probably owes its origin to the method of working formerly often adopted for such deposits, which were wrought by chambers arranged in *tiers* or *stories*.

The tin Stockworks of Cornwall may be divided into three classes, according as they are found in clay-slate (killas), granite, or elvan. I propose giving a short account of four of them which have never been thoroughly described.

Wheal Prosper and Michell.—These are open workings about half a mile west of Lanivet church, near Bodmin. For a distance of upwards of 800 yards and a width of 30 yards the killas is intersected by numerous little tin-veins running E. 7° N. (true); the pit is usually 60 or 70 feet wide in the bottom, but in one part, where a series of N. and S. branches go across, the width is double that amount. In addition to the E. and W. and N. and S. strings, there are occasional *caunters* which are likewise stanniferous.

The killas is usually very soft and generally light-coloured, *i. e.* grey or white, or stained a yellowish brown by oxide of iron. In some places near the veins the killas is converted into a soft tourmaline-schist. The veins themselves are mere strings, rarely more than $\frac{1}{8}$ inch thick. In addition to quartz and cassiterite, I have noticed a little gilbertite in them. The quantity of oxide of tin contained in the stuff is exceedingly small, not more than 3 lbs. per ton of rock on an average, say 0·13 per cent.; and it is really astonishing how such stuff can be worked without incurring a considerable loss. Taking the oxide of tin, or "black tin," at £42 per ton, the pound is only worth $4\frac{1}{2}d.$; so that the ground as it stands is only worth $1s.\ 1\frac{1}{2}d.$ per ton. This amount has to cover all expenses of blasting, breaking, tramming a quarter of a mile, besides stamping and dressing.

Some of the reasons why the stuff can be treated so cheaply are:—

1. The rock is soft and friable and easily stamped.

2. The tin-ore is in large grains, consequently the rock need not be stamped fine, and the subsequent washing operations are greatly facilitated.

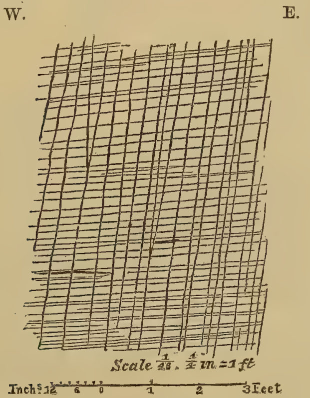
3. The substances mixed with the tin-ore are specifically very much lighter and easily separated by washing. There is no pyrites to necessitate calcination.

4. There is water power at command.

In spite of all these advantages there is much to marvel at in the results; and indeed I doubt whether there is any place in the world where such poor tin-rock is being treated as at Wheal Prosper.

Mulberry Mine, situated about $3\frac{1}{2}$ miles W.S.W. of Bodmin, and $1\frac{1}{4}$ mile N.W. of Wheal Prosper, is a large open quarry. The pit is about 30 yards wide at the bottom and about 300 yards long from north to south. Thirty yards, however, does not express the total width of the tinny ground, as some is still left standing on the east side of the pit. At the north end the pit is about 120 feet deep, and 80 feet at the other. The killas, which is of an ash-grey colour, dips at an angle of about 45° in a direction N. 22° W. (true). It is

Fig. 1.—*Veins in Mulberry Mine.*



traversed by numerous branches or veins running N. 7° W., dipping about from 80° to 90° W., and varying from mere joints to veins 4 or 5 inches in width, rarely more than a foot apart, in fact generally only a few inches. Many of the veins preserve their independence for a considerable distance without intersecting other branches; but at the same time it is easy to find junctions both in the dip and in strike; sometimes also two adjacent strings may be connected by a "floor" or vein of tin following the stratification. In addition to oxide of tin the veins contain quartz and a little arsenical pyrites and wolfram.

The appearance of the N. end of the quarry will be readily understood by reference to figure 1, whilst a second diagram (fig. 2) shows the general mode of working.

Men, standing at A, bore and blast holes, which throw the rock to B, under which a level has been driven with an opening C, usually closed by a hatch. A waggon is run in, and by opening the hatch it is filled without labour. As the face of the quarry gets further and further north from the removal of a succession of more or less vertical slices, the little level is driven on ahead and another hatch made.

The stuff is trammed away a distance of about a quarter of a mile to some stamps worked by water power; and even at present prices the poor tin-bearing rock, containing not more than 7 lbs. to the ton of stuff, say one third per cent. black tin, may be made to pay all expenses.

Fig. 2.—*Sectional view of Mulberry Mine.*

As in the case of Wheal Prosper, such a result could not be obtained were it not for the fact that the rock is soft and the tin in comparatively large grains.

*Minear Downs**.—About $1\frac{1}{4}$ mile N.E. of St. Austell is a deposit very much resembling that of Mulberry Mine, which I have just described. The great open quarry at Minear Downs is about 200 yards long at the top, and 60 or 70 yards wide, but only 90 yards long and 20 or 30 yards wide at the bottom. The greatest depth can scarcely be less than 120 feet. These dimensions will give an idea of the enormous amount of the tin-bearing rock which has been removed. The tin-ore occurs in a series of more or less parallel veins in the killas, striking about E. 7° S., and dipping N. at an angle of about 70°; the strings are often mere cracks, but occasionally $\frac{1}{8}$ in. wide, and lie from 2 inches to 12 inches apart. I counted ten strings in one place in a width of 6 feet. They generally keep their own course without much interlacing in dip and strike. The killas itself dips S.S.E. at an angle of 20° to 25°, so that the strings intersect it almost at right angles. At the sides of the strings the killas is often stained red and yellow, and is occasionally altered into tourmaline schist.

On the S.W. side of the pit is a so-called lode, which is merely a

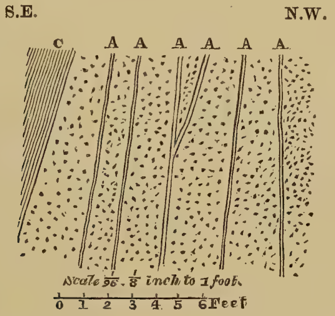
* The word "Minear" is, of course, a corruption of *Menhir*, a *Longstone*. In fact, the name of the farm is written "Menheir" on the Ordnance Map. I use the spelling adopted by the present owners of the mine.

mass of tourmaline schist 6 or 8 inches wide between two tinny branches.

Carrigan, about 2 miles E.N.E. of Roche, on the northern edge of the great Hensbarrow boss of granite, affords the finest display of Greisen in the county of Cornwall. Mr. J. H. Collins alluded to it in a paper read before the Royal Cornwall Geological Society last year, but only very briefly; and I believe that some extracts from notes that I made two years ago will not be without interest.

The mass of Greisen wrought at Carrigan Quarry (Crogan Rock, Ordnance Map, Sheet 30) is known for a width of 50 yards, and a length of 100 yards and a depth of 60 feet. On the S.E. side it is

Fig. 3.—*Section at Carrigan Mine.*



A A. Leaders. C. Flucan.

bounded by a large clay vein or *flucan*, C (fig. 3), and on the N. it disappears under the alluvium of the neighbouring valley. The rock is a mixture of quartz and mica with a good deal of schorl, some gilbertite, and a little iron-pyrites, fluor, and cassiterite. The mass is traversed by a number of so-called *leaders* A A, which are quartz-veins with tin-ore, schorl, gilbertite, and clay, dipping 85° S. and running E. 7° N. Very often they are an inch or two inches wide, and from 1 foot to 6 feet apart. Occasionally the *leader* adheres to the enclosing rock (*country*) by one side only, and has a clay vein on the other. On washing the clay, broken crystals of cassiterite are generally found, proving, I think, that since the deposition of the tin-ore in the fissures there has been a movement of the walls. When tin was at a higher price this mass of Greisen and tin-veins was quarried and stamped on a large scale; in fact, 27,500 tons of rock were stamped, yielding 64 tons of tin-ore, or 5·2 lbs. of tin (*black tin*) per ton, say ¼ per cent. It was expected that the wholly virgin ground would produce 8 lbs. of tin-ore per ton. As the rock is very much harder than the killas of Mulberry, for instance, it cannot be profitably worked at present prices. In my opinion this mass of Greisen is merely altered granite. When we can observe (and in no places more clearly than at St. Michael's Mount and Cligga) the conversion of granite into Greisen along the sides of the small tin-lodes, it is easy to suppose, where the altering action was either very energetic or long continued or the lodes very numerous, that the whole of the intervening rock might be converted into a large mass of Greisen.

Discussion.

Mr. Warington W. Smyth said that as many of the principal stockworks have been already described, he would pass over the paper dealing with them and proceed to those treating of the origin of other stanniferous deposits, for which some originality seemed fairly to be claimed by the author. He remarked that it had long been known that, although mineral veins often occur between definite walls, sometimes one or both of their walls had been attacked by the same forces concerned in the aggregation of the minerals. It seemed likely that the same forces which brought about the deposition of the ores may have also simultaneously altered the neighbouring rocks, and led to the appearance in them of singular minerals, such as those mentioned by the author, and notably substances containing fluorine and boracic acid. Miners have observed that occasionally the capel or cab is more valuable than the leader or lode itself. In some undoubted instances the capel may have advanced from the fissure into the rock. In killas bordering on granite much schorl often occurs.

Mr. Drew inquired whether the more irregular masses of minerals do not occur not parallel to the lode, but as if in the lesser branches of fissures.

Prof. Bonney found a confirmation of Dr. Le Neve Foster's observations in the structure of luxulianite, the remarkable rock of which the Duke of Wellington's sarcophagus in St. Paul's Cathedral is made. Some schorl rocks are altered granite, others altered killas. He noticed the singular molecular changes in the quartz, schorl, and orthoclase of luxulianite. No doubt acidulated waters, charged with the necessary minerals, altered the granite and formed the veins.

Prof. Seeley remarked that 25 years ago he had been taught by Mr. Warington Smyth and Prof. Ramsay that the rocks near veins of minerals are often altered. Near fissures, no doubt, the rocks had been subjected to great strains, which lessened the cohesion, and thus favoured the infiltration of waters conveying mineral matters in solution into the rocks beyond the actual fissure.

Mr. Sollas remarked that he had long been puzzled to know what the *ordinary* theory of mineral veins might be. The facts brought forward this evening supported an idea which some time ago had occurred to himself. The surface of volcanic regions often bears volcanic cones and also mineral springs, the materials of both being brought up through fissures. When denudation removes the surrounding country, masses of gabbro and granite bosses are laid bare, and mineral veins appear at the surface. Mineral veins seem to be the roots of mineral springs. We yet want to know more about the solubility of minerals under great pressure and at a very high temperature. Many are probably soluble under such conditions which are not so under the ordinary conditions at the surface; and if this be the case we need have no great difficulty in understanding their deposition and also the alterations in the rocks.

Prof. Ramsay, referring to Mr. Sollas's inquiry as to the common theory of mineral veins, said that long since it used to be taught that the minerals were brought up from below by the agency of vapours; afterwards that the minerals in the lodes and in the altered rocks about them were accumulated by the aggregation of minerals diffused in minute quantities throughout the rocks on either side. He referred to a deposition of copper from aqueous solution in a peat-moss in Wales, the solution having proceeded from a distant hill. The peat was worked, and much copper obtained from it; and in consequence of this the hill was bored in many directions in search of a lode of copper-ore, but nothing was met with except a few thin strings not worth a farthing. It had been long since shown that in Derbyshire fissures in anticlinals were unproductive, but those in synclinals productive of lead-ore; and this was explained by the lead being dissolved by the water falling on the surface, which, travelling along the planes of stratification, conveyed it from the convexities and towards the hollow folds of the beds.

Mr. De Rance stated that the mode of occurrence of lodes in Alston Moor was confirmatory of what Prof. Ramsay had just said.

39. *The* SECONDARY ROCKS *of* SCOTLAND. Third Paper. *The* STRATA *of the* WESTERN COAST *and* ISLANDS. By JOHN W. JUDD, Esq., F.R.S., Sec. G.S., Professor of Geology in the Royal School of Mines. (Read January 23, 1878.)

[PLATE XXXI.]

CONTENTS.

I. INTRODUCTION.

THE existence in the Hebrides and adjoining portions of the Western Highlands of more or less isolated patches of limestone, sandstone, and shale, frequently containing fossils, which are interposed between the gneissic and volcanic formations of the district, has been known to geologists for more than a century. During this period many authors, both British and foreign, who have visited the very interesting region in question, have described the peculiar characters presented by some of these curious deposits, their singular relations to the volcanic rocks of the same area, and the remarkable changes which they are in some cases seen to have undergone in proximity to the great igneous masses. In the embittered controversies which so long raged between the Huttonians and Wernerians, too, these deposits were frequently referred to by both parties as lending support to one or other of the rival hypotheses.

That these deposits of fossiliferous rock would have to be classed with the *Secondary* series, in the extended and rather vague sense in which that term was then employed, came to be very generally recognized about the beginning of the present century; and at a somewhat later date Macculloch pointed out the analogy of the organic remains which he had found in some of these strata with those of the English *Lias*. Beyond these identifications, however, the Scottish geologists seem to have seldom desired to proceed; and, indeed, there was a very general disposition among them to regard any attempts at classifying these strata, and correlating them with the deposits of other districts, rather as idle and useless exercises of ingenuity than as promoting the real progress of geological science.

The teaching of William Smith, that strata may be identified by their organic remains, has never found very ready or hearty acceptance north of the Tweed; and as recently as 1839 we find so able a geologist as Mr. Hay Cunningham giving expression to the views of his countrymen (both those who, like himself, inclined to the Wernerian doctrines and those who accepted the teachings of Hutton) in the following terms:—

"The stratified rocks which we have described as occurring in Eigg are in many other of the Hebrides connected with strata which differ from these, both in mineral and fossil characters. Little examination is required to convince that they form only one series, and that to subdivide them into distinct groups is, since nature has made no separation, a work of little utility. Though we could refer every stratum to its analogue in any other country, say to those of England, nothing would be gained; for as there the several members of the series, though they have distinct names attached to them, belong to one great geognostical group, and present only insignificant mineral and fossil differences, so here the same is evident, and entitles us to consider that there is no necessity to parcel out into minute classes the rocks of a stratified deposit which expresses, when its members are viewed collectively, a system which had been formed uninterruptedly during a well-marked epoch of the world's ancient history"*.

Passages of similar import abound in the writings of Macculloch and other countrymen of Hay Cunningham; and it is evident to every student of Scottish geology that this neglectful and even contemptuous attitude towards palæontological evidence has done not a little towards retarding the progress of our knowledge of the geological history of the northern portion of our island.

To Murchison belongs the merit of having seen at a very early date the groundless character of the prejudices of his countrymen against the employment of palæontological evidence; he visited the Western Highlands in the years 1826–27, and succeeded in identifying a number of the stratified deposits in the Hebrides with their equivalent English deposits. Unfortunately Murchison's acquaintance with the Mesozoic formations and their characteristic fossils was at that time very limited, and he in consequence fell into some serious errors in his correlation of the Scottish strata; and, what is still more to be regretted, he altogether failed to recognize the true age

* Memoirs of the Wernerian Society, vol. viii. p. 148, note.

of certain other deposits of great interest which certainly fell under his notice. In spite of these drawbacks, however, Murchison's labours were of the greatest importance and value, in establishing the existence and order of succession of the Liassic and Oolitic strata of the Western Isles.

Up to the year 1870, when I commenced my researches in this area, no Secondary rocks other than those of Jurassic age, had been certainly proved to exist in the Western Isles of Scotland. During the last seven years, however, I have been engaged in working out the relations and order of succession of the various scattered fragments of fossiliferous strata which underlie the enormous masses of Tertiary lavas, and have been gradually led to the following conclusions:—At the base of these sedimentary rocks, intercalated between the Palæozoic schists and the Tertiary lavas, occur strata containing the well-known plants of the Coal-measures, and undoubtedly representing the Carboniferous system—a system hitherto supposed to be wholly absent from the Scottish Highlands. Above these Carboniferous strata are found a great development of the Mesozoic formations, the united thickness of which could have fallen little, if at all, short of a mile. In this vast mass of stratified rocks are included very highly interesting representatives of all the great Secondary systems, with the exception of the Neocomian; we have extensive deposits belonging to the Poikilitic, the Jurassic, and the Cretaceous (the first and last of these being now described for the first time as existing in this area). Further we find that grand unconformities exist in the midst of this series, and indicate the lapse of great periods, which were not epochs of subsidence and of sedimentary deposition in the area which we are describing.

My object in the present paper will be to endeavour to reconstruct, from the scattered and fragmentary records in this area, the history of the succession of geological events during the vast periods of the Mesozoic epoch. I had originally intended to supplement this account of the stratigraphical succession of the deposits with descriptions of such new fossils as have come under my observation during the prosecution of my task; but I now find that this would increase my paper to inordinate proportions, and I have therefore determined to postpone this part of my work; and I do so the more readily, as I find the steadily increasing number of students of palæontological geology in Scotland happily promises to relieve me of this part of my task altogether.

The researches on which this paper is founded have occupied much of my time and thought during the last seven years; and in my last visit to the district, during the summer of 1877, with a view to the final revision of my notes previous to their publication, I had the pleasure of being accompanied and assisted by two students of the Royal School of Mines—Dr. J. Taylor Smith and Mr. R. D. Oldham, the former of whom was with me during a great part of the autumn's work.

II. History of Previous Opinion on the Subject.

For the earliest notices of the very interesting rocks which it is the object of the present memoir to describe, we must go back more than a century to the famous work of Pennant, who mentions the occurrence of compressed Ammonites in the rocks of Duntulm in the north of Skye*. At a little later date the Liassic sandstones of the southern coast of Mull are referred to by Mr. Abraham Mills in letters which were read before the Royal Society in the year 1790†.

In Jameson's 'Mineralogy of the Scottish Isles,' published in the year 1800, there are a number of very interesting observations on the Secondary rocks of Mull, Eigg, and Skye, the remarkable relations of which to the volcanic masses of the area were by no means overlooked, though they were too frequently misinterpreted.

Several foreign geologists who have been attracted to the Western Isles of Scotland by the grandeur and interest of the volcanic phenomena displayed in them, have given in their works many valuable notes concerning the associated Secondary strata of the district. Among these we may especially mention M. Faujas de Saint-Fond ‡, M. Ami Boué §, M. L. A. Necker-de-Saussure ||, and MM. Von Oeynhausen and Von Dechen ¶, each of whom has contributed some useful observations on the strata in question.

The geologist who has, however, done far more than any other in seeking for and investigating the relations of the isolated patches of Secondary strata in the Western Isles of Scotland is Dr. John Macculloch. During many years he was indefatigable in his exertions to explore those interesting regions, which imperfect means of communication, with stormy seas and a most trying climate, had combined to render a *terra incognita* to the geologist. The first series of the Transactions of our Society contains several papers bearing striking witness to the earnestness and enthusiasm with which he prosecuted his self-imposed task; and the great work in which he finally embodied the results of his observations** will always remain no less a landmark of the progress of geological knowledge than a monument of the zeal and ability of its author.

As my own task has led me to follow very closely in the footsteps of Macculloch, I think that it is incumbent upon me to speak a word in defence of the fair fame of one to whose previous researches I have been on so many occasions very deeply indebted. In a former volume of this Journal, not only have Macculloch's labours been

* Pennant's 'Tour in Scotland and the Hebrides in 1772,' p. 304. Published in 1774.

† Phil. Trans. vol. lxxx. pt. 1, p. 85 (1790).

‡ Voyage en Angleterre, en Écosse et aux îles Hébrides. Paris, 1797. See also his 'Essai de Géologie.' Paris, 1809.

§ Essai géologique sur l'Écosse. Paris.

|| Voyage en Écosse et aux îles Hébrides. Geneva, 1821.

¶ Karsten's Archiv, vol. i. 1829.

** A Description of the Western Islands of Scotland, including the Isle of Man. London, 1819. Two volumes with Atlas.

spoken of in a tone of disparagement, but even his veracity has been called in question. In a subsequent page in this memoir I shall show that the circumstances on which this particular and most serious attack is based have been altogether misunderstood; and I here state my conviction—a conviction arrived at after many years of labour in the same field—that the charges brought against Macculloch by several of his countrymen have no real foundation. Macculloch's rhetorical and inflated style of writing may be objected to as being little suited for scientific description; his unfounded prejudices, his bitterness in controversy, and his want of amiability may be equally regretted; while every one must lament that one so gifted should during the later years of his life have wronged science and his own reputation by taking up a position of sullen isolation, and by refusing to recognize the value or accommodate himself to the requirements of rapidly growing knowledge. But every member of this Society will rejoice if the able geologist who took so prominent a part in its first establishment, and one of whose papers was the first thought worthy of the honour of publication in our Transactions, he who was the first to secure government aid to our science in Britain, and to establish and carry out single-handed a geological survey of the northern part of the kingdom, can be acquitted—as I believe he can be—of the very serious charges which have been brought against him.

Any one who will try to realize the difficulties under which Macculloch laboured—the want of any thing approaching to accurate maps and charts, the difficulties of travel in these stormy seas before they had been comparatively opened up by the introduction of steam-vessels, and the imperfection of geological knowledge at the early date at which his researches were carried on—and then candidly examine the 'Description of the Western Isles,' must, I think, be filled with admiration for the energy and genius of its author. Nor can we forget that in citing the name of Macculloch we furnish some reply—alas, almost the only one possible—to the charges so often brought against our native geologists by foreigners, of contempt for, and actual injury done, to the Petrographical branch of our science.

Macculloch, like Dr. Johnson, has been made the victim of the resentment of a generous but over-sensitive race, which seems to have expected, from one with whom they claimed ties of kindred, unsparing flattery instead of honest criticism. With this cause of quarrel against Macculloch we have, however, nothing to do; suffice it for us if his scientific honour and veracity be vindicated.

The publication of Murchison's two papers on the strata of the Oolitic series in the Hebrides* forms an important epoch in the progress of our knowledge of the rocks treated of in the present

* "On the Coal-field of Brora, Sutherlandshire, and some of the Stratified Deposits in the North of Scotland," Trans. Geol. Soc. 2nd ser. vol. ii. p. 292; and "Supplementary Remarks on the Strata of the Oolitic Series and the Rocks associated with them, in the counties of Sutherland and Ross and in the Hebrides," *ibid.* p. 353.

memoir. Although Murchison appears only to have visited a few of the more conspicuous and accessible of the sections described by Macculloch, yet his application to the beds in question of the principle of identifying them with those of other districts by a comparison of their organic remains led him to some very important and interesting conclusions. Thus, in addition to the recognition of the Liassic beds already made by Macculloch, Murchison was able to define the existence of several members of the Lower Oolites, and to compare their fossils with those of well-known formations in England. His identification of certain Scottish strata with the English Cornbrash and Wealden respectively may be excused on the ground of the imperfection of palæontological knowledge at the time when he wrote; but the same apology can scarcely be made for the confusion into which he fell with regard to the Middle Lias and Lower Oolite, or for his failure to recognize the true age of certain other fossiliferous rocks that came under his notice. Short, however, and somewhat superficial as were Murchison's researches in the district, he deserves to rank, on account of the excellence of the methods he introduced into the study of the district, as second only to Macculloch himself among the investigators of Hebridean geology.

With the exception of the examination of the Secondary strata in the Island of Eigg by Hay Cunningham*, Hugh Miller†, and Professors Geikie and Young‡, the subsequent work which has been done in the elucidation of the Jurassic rocks of the Western Highlands has consisted in the re-examination by more competent palæontologists of the sections to which Murchison had called the attention of geologists by his important discoveries.

In 1851 Prof. Edward Forbes visited Loch Staffin and showed by the fossils which he obtained that the freshwater beds there could not be of Wealden age as suggested by Murchison§.

In 1858 Dr. Thomas Wright, by the study of a series of fossils collected by Professor Geikie in the district of Strath in Skye, was enabled to speak with much more exactness as to the particular subdivisions of the Lower and Middle Lias which are there exhibited ||.

In 1862, Messrs. Davidson and Etheridge, in like manner, examined a series of fossils collected by Captain E. J. Bedford, R.N., from the Middle Lias at Carsaig Bay, in the Island of Mull, during the survey of the coasts of that district for the Admiralty ¶.

Still more recently Professor Tate has studied carefully the series of fossils collected during several years by the indefatigable geologist Dr. Bryce, who has so recently sacrificed his life in the prosecution of his favourite studies**. As the collections submitted to Professor Tate were very carefully made, and he had, moreover, the opportunity of studying the sections themselves, his identifications of the

* Memoirs of the Wernerian Society, vol. viii.

† See his 'Cruise of the 'Betsy,'' and other works, in which many valuable observations on this island are recorded.

‡ Quart. Journ. Geol. Soc. vol. xxvii. p. 288.

§ *Ibid.* vol. vii. p. 104.

|| *Ibid.* vol. xiv. p. 24.

¶ The Geologist, vol. v. p. 443.

** Quart. Journ. Geol. Soc. vol. xxix. (1873) p. 317.

several geological horizons are particularly valuable and satisfactory —the more so from his well-known extensive knowledge of Jurassic palæontology.

It may be right to mention that the discovery by myself of Cretaceous and Carboniferous strata in the Western Islands has already been announced, though without any details being given—the first in a letter to Sir Charles Lyell, which was read at the meeting of the British Association in 1872 by Professor Hughes*, the latter in a letter to the 'Geological Magazine'†; while the general nature of these recent discoveries and their bearing on the geology of the Highlands have been discussed by the Duke of Argyll, in his paper read at the meeting of the British Association at Glasgow in 1876‡.

III. Distribution and Physical Relations of the Secondary Strata of the Western Highlands.

In the last published part of this memoir I endeavoured to give such a sketch of the relations of the Tertiary volcanic rocks to the strata of Mesozoic age as would enable the reader to realize those peculiar accidents by which the preservation of the numerous isolated fragments of the latter have been determined. I showed that at the commencement of the Tertiary epoch considerable areas in the north of Scotland must have been covered by deposits of Secondary age, attaining in places to a very great thickness, and that during Eocene and Miocene times there had occurred, in the district of the Western Highlands, a series of volcanic outbursts on the very grandest scale; that these tremendous exhibitions of igneous violence were succeeded, probably during the Pliocene period, by numerous smaller and sporadic eruptions; and that, as the consequence of this prolonged volcanic action, portions of the Secondary strata were in some cases buried under enormous thicknesses of slowly accumulated lava-sheets, while other portions were caught and entangled between the intrusive sheets proceeding from the great centres of igneous activity. In some instances, as I then pointed out, the Secondary rocks were subjected to metamorphic action, through their contact with the intrusive plutonic masses, and occasionally the metamorphism thus produced was of the most extreme character: in other cases the Secondary strata were broken up by the explosive action of the volcano, so that we now find only their fragmentary relics imbedded in the ejected agglomerates constituting portions of the old cones of eruption; and it is from these fragments alone that the geologist is enabled to form a judgment concerning the nature and fossil contents of the rocks through which the volcanic agencies forced vents. But in every case it is in consequence of the extensive denudation to which, as we have shown, the volcanic rocks of the Hebrides have been subjected, during comparatively recent times, that the

* Rep. Brit. Assoc. (1872), Transactions of Sections, p. 115.
† Vol. i. new series, p. 573.
‡ Rep. Brit. Assoc. (1876), Transactions of Sections, p. 83.

isolated fragments of the Secondary strata are now revealed to us; and, except where protected by the harder and less perishable volcanic rocks—either burying them under enormously thick accumulations of lava or entangling them between igneous sheets—almost every vestige of the Mesozoic strata has been removed by the denuding forces. Nevertheless, wherever portions of the great basaltic plateaux have escaped being swept away by the denuding forces, as in the islands of Muck and Eigg, there masses of the Secondary strata are found cropping out from beneath them; while around the igneous centre of Ardnamurchan, and perhaps also that of Rum, the same strata, metamorphosed indeed almost beyond recognition, are found entangled between igneous sheets and intersected by a plexus of dykes.

I cannot here refrain from citing a vivid illustration of the manner in which the preservation of these curiously isolated fragments of the Mesozoic deposits has been effected, which was suggested to me by the late Sir Henry James a few years ago, when I had an opportunity of conversing with him upon the subject. He compared the fragments of such strata, which have escaped removal by denudation, to the little bits of paper that would escape being washed away if a newspaper with a number of heavy stones on it were laid in the bed of a running stream.

The isolated patches of Secondary strata are now found widely scattered over an area measuring 120 miles in length from north to south, and 50 miles in breadth from east to west. Within these limits, however, such patches occur only where those peculiar conditions have prevailed which, as we have shown, have determined the preservation of these fragmentary relics—namely, in proximity to the great Tertiary volcanos of Skye, Rum, Ardnamurchan, and Mull. Thus the whole northern part of the island of Skye consists of a plateau of basaltic lavas poured out from the volcanic centre of the Cuilin Hills; all round the edges of this great basaltic plateau the Secondary rocks, which they have overwhelmed, can be traced here and there in cliff-sections; and at a few points in the interior, where valleys have been cut deeply into the plateau, inliers of the same Mesozoic deposits make their appearance. From the careful study of the phenomena presented at these various points, it becomes clear that the denuded surfaces of these Secondary rocks formed the terrestrial areas on which the lavas were poured out. In Raasay the same relations are exhibited in an equally striking manner, the Secondary rocks making their appearance all round the shores of the island, under the covering of Tertiary lavas which forms its higher portions. Even where the most minute isolated patches of the Tertiary lavas occur, as at Strathaird and Ru-Geur in the southern part of Skye, the Secondary rocks are found to be preserved beneath them. Still more strikingly is this found to be the case in Mull, where patches of Secondary strata can be traced at short intervals all round the shores of the island and in the adjoining district of Morvern, in such a manner as to lead to the irresistible conviction that the great volcano of that district was opened in the first instance in the midst of strata of Secondary age, and that its lavas almost everywhere rest on deposits of the same age. The manner in which the central subsidence, which has been so very marked in the case of the volcano of Mull, has operated in the more perfect preservation of its lava plateaux from denudation than is the case in the contemporaneous volcanos we have described on a former occasion; and the underlying Mesozoic rocks have, of course, also been saved from destruction with their protecting capping of lavas, though at many points they have been by the same action depressed beneath the sea-level and thus withdrawn from the ken of the geologist.

The volcanos of Rum and Ardnamurchan were of smaller dimensions than those of Skye and Mull, and they have, in consequence, suffered more from denudation. On the other hand, wherever the pleateaux of protecting lavas have been removed, as is the case in the greater part of the district of Sleat in Skye, and in the northern part of Rum, there all traces of the Secondary rocks have disappeared also. It is when viewed in this relation that such minute outliers of the volcanic rocks, preserving between themselves and the underlying gneissic rocks slices of Secondary strata, are of such especial interest. Such examples occur at Ru-Geur, in Skye, and in the remarkable mountains of Morvern, to be described hereafter.

From an examination of all the circumstances of the case, it appears to me to be impossible to avoid the conviction that these patches of Secondary strata, although now so minute in dimensions and isolated in position, once formed portions of a great series of connected deposits which covered the greater part of the vast area we have indicated, and attained in places a thickness of from 4000 to 5000 feet.

But an attentive consideration of the facts of the case will, I believe, compel us to go a step further in the same direction. We find, 80 miles to the southward of the exposures of the Secondary strata in Mull, and exactly at the point where there exists a recurrence of those conditions which have determined the preservation of the Mesozoic rocks in the Western Isles, an almost precise repetition of the familiar phenomena presented by the Scotch deposits in question. In the island of Rathlin and the north-east of Ireland we meet—just as in the Hebrides and Western Highlands—with a series of Carboniferous, Poikilitic, Jurassic, and Cretaceous strata interposed between the Palæozoic schists and the Tertiary basalts. And, as we shall show hereafter, the relations between the Scotch and Irish Secondary deposits are of the most intimate and unmistakable character. Can we then avoid the conclusion that the absence of traces of the Secondary strata in the intervening area is not to be accounted for by the inference that they were never deposited in that district, but that it is to be set down entirely to the absence of those peculiar conditions by which alone, as we have seen, any portions of the strata of that age could have escaped destruction during the great ordeal of denudation to which the district has been subjected?

Nor do I think that it will be possible to pause here. For, as has been shown in the first part of this memoir, there are various deposits of Mesozoic age in the counties of Sutherland, Ross, and Elgin, the nearest of which lies 100 miles to the north-east of the most northern patch of Secondary strata in the Western Isles; and these fragments of Secondary strata in the Eastern Highlands have, as was there pointed out, escaped destruction by denudation only in consequence of being let down many hundreds, or even thousands, of feet below their original positions, and thus coming to be preserved in the very heart of the much harder Palæozoic masses. If, on the other hand, we proceed from the patches of Secondary strata in the Hebrides in a south-easterly direction, we find in Cumberland and on the borders of Cheshire and Shropshire fragments of Liassic deposits faulted down into the midst of the older rocks; and these form a connecting link with wide-spreading tracts of the same strata in the south-eastern part of England.

In the face of these facts, I believe that it is impossible to avoid the conclusion that the whole of the north and north-western portions of the British archipelago—now sculptured by denudation into a rugged mountain-land—were, like the south and south-eastern parts of the same islands, to a great extent, if not completely, covered by sedimentary deposits, ranging in age from the Carboniferous to the Cretaceous inclusive; and that, as a consequence, we must refer the production of the striking and very characteristic features of those Highland districts to the last great epoch of the earth's history—the Tertiary—and very largely, indeed, to the latest portion of that epoch, namely the Pliocene.

It may be objected to this view concerning the recent date, geologically speaking, of the origin of the existing surface-features of the Scottish Highlands, that it is impossible to conceive of such a vast amount of marine planing down and of subaërial gouging of a series of rocks of the hardest character having been accomplished within what we are sometimes tempted to regard as comparatively short geological periods. But in reply to such an objection, I would point to the enormous effects that have clearly been produced since Miocene times in the Western Isles of Scotland, in the destruction of the old volcanic cones of that area, and more especially in the sculpturing of mountain-forms out of their intensely hard cores of gabbro and hypersthenite; to the work that has been accomplished in the same area, probably since Pliocene times, as borne witness to by the Scur of Eigg and the rocks of Beinn Shiant in Ardnamurchan; to the fact, which I have described in a former paper, that since the period of the Upper Jurassic, thousands of feet of the Middle Old Red Sandstone or Caithness flagstones must have been removed from the surface of Sutherland, as is clearly demonstrated by the preservation of a portion of those beds by the singular double fault already described*. But most strikingly of all is this fact of enormous denudation of the Scottish Highlands during very recent geological periods demonstrated by the occurrence of numerous post-Miocene faults, having

* Quart. Journ. Geol. Soc. vol. xxix. pp. 132–134.

downthrows of various amount, up to nearly 2000 feet, the effect of which upon the surface has been entirely masked by post-Miocene denudation.

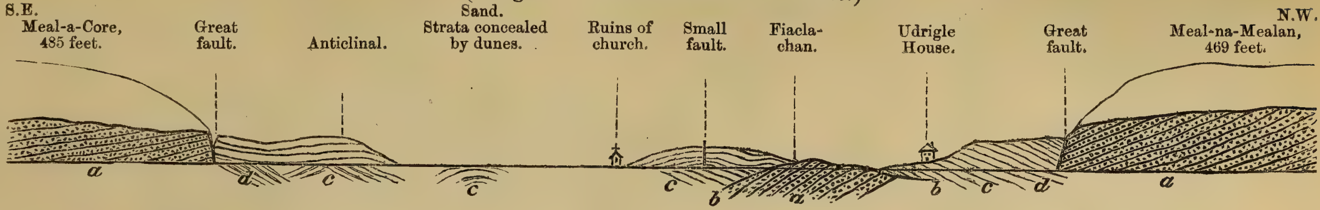
He who wishes to obtain some faint idea of the vastness of the periods of time represented by our great geological systems, cannot do better than go to the Western Highlands. After taking careful note how little has been accomplished by meteoric agencies since the Glacial epoch in obliterating its characteristic markings, let him study the enormous changes which have clearly resulted from the action of the same forces operating during and subsequently to the Pliocene period.

That during all the geological periods, from the Carboniferous to the Cretaceous inclusive, a very large part of the Highland districts was submerged, and formed areas of deposition, I think it is impossible to doubt; but that some portions of that Highland region did, during those long periods, exist more or less continuously as islands, we shall see in the sequel that there are good grounds for believing. Yet so uniformly similar is the succession of life-forms during the Mesozoic deposits, as exposed in Central Germany, in Northern France, in England, Scotland, and Ireland respectively, that it seems to me impossible to doubt that the Jurassic and Cretaceous deposits of all those areas were accumulated in the same sea—one in which the diffusion of the forms of life was not impeded by the existence of any great continuous barrier of land.

So far as I have been able to ascertain, there is only one exception to the statement that has been made that the Secondary strata of the Western Highlands owe their preservation to the agency of the Tertiary volcanic outbursts. This single exception occurs in the case of the Poikilitic strata of Gruinard Bay—where the soft unmetamorphosed strata in question have escaped total removal by denudation, in consequence of the action of the same causes as have, on the eastern coast of Scotland, effected the preservation of the Secondary strata. The beds of Gruinard Bay constitute the most northern exposure of Secondary rocks on the west coast of Scotland; they occur at a considerable distance from any of the great Tertiary volcanic centres; they are not traversed by the dykes, nor do they exhibit any evidence of having been ever covered by the lava-currents of that period. The beds in question, indeed, appear to owe their escape from destruction by denuding forces solely to the fact that they have been let down amidst the hard metamorphic rocks of the district by a great trough-fault, as shown in the following section (fig. 1), which I have constructed from data obtained by Dr. Taylor Smith and myself, and laid down on the excellent Admiralty chart of that part of the coast.

In all other cases of the preservation of patches of Secondary strata on the west coast of Scotland, the presence of Tertiary volcanic masses above or between them has evidently played a very important part in bringing about the result. In not a few instances, however, great movements and dislocations of the strata themselves have occurred, either before, during, or subsequently to those volcanic outbursts; and these, it is clear, have contributed, sometimes in a

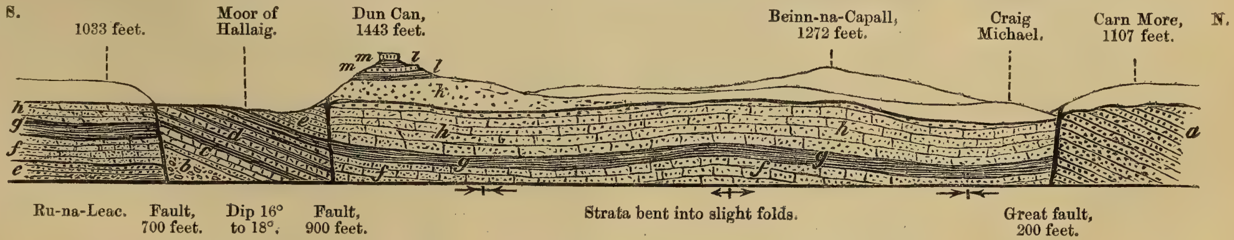
Fig. 1.—*Section illustrating the relations of the Poikilitic Strata of Gruinard Bay to the underlying Torridon Sandstone.* (Length of the Section about 3 miles.)



a. Torridon Sandstone.

Poikilitic {
d. Reddish, argillaceous, and sandy beds, with some strata of hard white sandstone.
c. Red and variegated marls and sands, with concretionary limestone.
b. Breccias and conglomerates.

Fig. 2.—*Great Cliff-section on the East Side of the Island of Raasay.* (Length of the Section about 5 miles.)



b. Poikilitic strata.
a. Torridon Sandstone.
m. Miocene lavas and intrusive sheets.

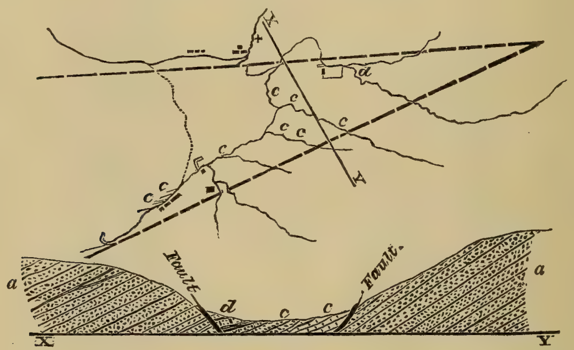
Liassic {
g. Upper Lias.
f. Scalpa series. } Middle Lias.
e. Pabba series. } Middle Lias.
d. Lower Lias.
c. Infralias.

Oolitic {
l. Estuarine shales.
k. Sandstones.
h. Inferior oolite.

very important degree, to the preservation of the fragments of Mesozoic rocks.

Thus in the case of the remarkable mass of Mesozoic rocks at Applecross, though it is highly probable (alike from its proximity to the Skye volcano and the fact of its being traversed by numerous basaltic sheets and dykes) that this patch of strata was originally buried under an accumulation of lava-sheets, which have since been entirely removed by denudation, yet it is manifest that the great faults which have clearly let down these strata many hundreds and perhaps thousands of feet below their original level into the heart of the mountains of Torridon Sandstone have had much to do with their preservation (fig. 3).

Fig. 3.—*Plan and Section to illustrate the relation of the patch of Liassic Strata at Applecross.*



a. Torridon Sandstone. *d.* Lower Lias. *c.* Infralias.

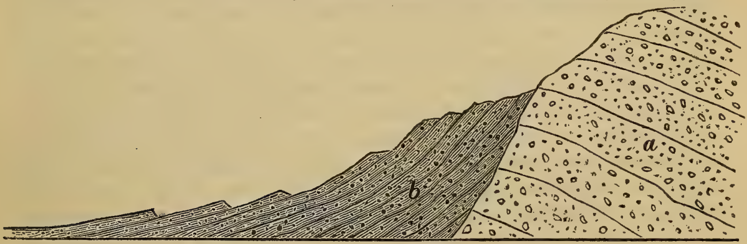
The broken lines in the plan indicate the positions of the great faults. The line X Y shows the line of the section represented below the plan.

The action of great faults, in combination with a covering of sheets of lava, in effecting the preservation of masses of Secondary strata is very strikingly exhibited in the grandest of all the sections of Mesozoic rocks in the Western Highlands, that of the eastern side of the island of Raasay, lying opposite to and only a few miles distant from Applecross. This section is illustrated by the accompanying diagram (fig. 2, p. 671), in which the amount of disturbance to which the strata have been subjected is strikingly apparent.

The relations of the strata in the island of Scalpa, which I had the opportunity of studying with one of the students of the School of Mines, Mr. A. Grant, at the time resident in the island, are quite similar to those just described in the island of Raasay, the Middle-Lias beds being thrown against the Torridon sandstone by a great fault as shown in fig. 4.

The most striking example, however, that can be adduced of the action of faults in contributing to the preservation of the Secondary strata of the Western Islands from destruction by denuding forces is that afforded by the magnificent section of the Innimore of Ardtornish. Here we find a series of lava-sheets poured from the great volcanos of Mull and Ardnamurchan during the Miocene period (the greatly denuded masses of which retain a thickness of over 1200 feet) lying upon a series of strata ranging in age from the Carboniferous to the Upper Chalk. There Secondary and Tertiary strata have been cut across by a fault, probably having a throw of nearly 2000 feet, by which they have been brought into apposition with vast mountain-masses of gneiss, probably of Cambrian and Silurian age (see fig. 5).

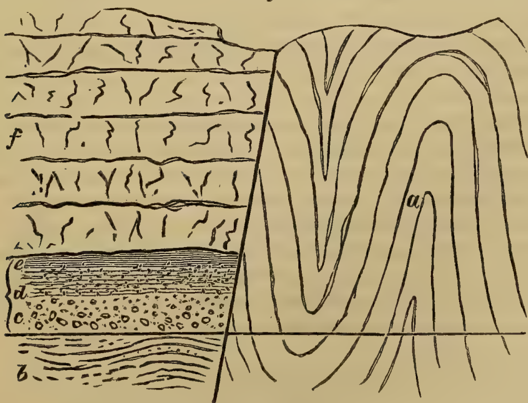
Fig. 4.—*Junction of Torridon Sandstone and Middle-Lias Strata, as seen a little to the West of Scalpa House, in the Island of Scalpa.*



a. Torridon Sandstones. *b.* Middle-Lias beds (Scalpa series).

The dip of the Middle-Lias strata is found to increase gradually, as we approach the line of fault, from 3° up to 35° or more.

Fig. 5.—*Section exposed at the Innimore of Ardtornish, on the Sound of Mull.*



f. Miocene basalts.
e. Marls. } Poikilitic.
d. Sandstones. } Poikilitic.
c. Conglomerates. } Poikilitic.

b. Carboniferous rocks seen in reefs on the shore.
a. Gneiss and schist (Palæozoic).

At a distance of only a few miles another fault of smaller dimensions crosses the outlying mass of Beinn-y-Hattan.

Apart, however, from the great dislocations, the effects of which, as we have seen, are so clearly manifest in the Western Highlands, it is evident that, wherever preserved from denudation, the basaltic plateaux of Miocene lavas, with their foundations of Secondary strata, have owed their survival in a very great degree to powerful earth-movements which have taken place. In the case of the Skye volcano only a sector of about 50 degrees has escaped removal by denudation out of the vast circular area of lavas which doubtless originally surrounded it on all sides. The isolated masses of Secondary rocks, capped by lava, in Dun Can, Strathaird, and Ru-Geur, with the plexus of dykes and sheets that intersect all the older rock-masses of Strath and Sleat, bear witness in the strongest possible manner to the fact that the volcanic action extended equally on all sides from the Cuilin and Red Mountains of Skye. As was well recognized, too, by Macculloch, Murchison, and Forbes, as well as by later authors, the great lava-plateau forming all the northern part of the island of Skye exhibits in itself very striking evidences of the irregularities of the great earth-movements which have taken place in the district. Thus, while on the eastern coast of Trotternish the Secondary rocks are found in the cliff-sections up to 1000 feet above the sea-level, on the western coast they only just make their appearance at a few points at that level, and for the most part, indeed, are concealed altogether by the Tertiary lavas. The same inclined position of the lavas of the basaltic plateaux is quite as strikingly seen in Raasay as in Skye. Of minor flexures and fractures which have occurred in both districts since the ejection of the Tertiary volcanic masses, the number is almost infinite, and the striking effect produced by them is sufficiently patent to every one who studies those wonderful coast-sections.

In Mull the plateaux of basaltic lava have apparently suffered less from denudation than have those of Skye; and this is the result of that central subsidence which, as I have shown in a former paper, has produced such marked effects in the case of that volcano; but even in Mull, that great breach in the lava-plateaux which constitutes the Sound of Mull, their interruption by numerous sea-lochs, and their total removal on the south and east sides of the igneous centre speak very impressively indeed of the enormous amount of waste of the Tertiary volcanic rocks and of the subjacent Secondary strata by denudation. The same conclusion is very strikingly confirmed by an examination of the isolated patches of the basaltic plateaux forming the islands of Staffa and the Treshnish group, all of which have doubtless been separated from Mull by post-Miocene denudation aided by earth-movements.

Most strongly do the causes of the preservation of these strata make themselves felt in the case of that great line of fault which forms the north-western boundary of the Mull plateaux, and in that singular series of outliers of basaltic rocks forming the summits of mountain-peaks in Morvern, and reserving beneath them those remarkable patches of Secondary strata, on the singular isolation of which I have already spoken; and the diagram section, Pl. XXXI. fig. 2, will sufficiently serve to illustrate the peculiar manner in which the patches of Secondary strata are exhibited in these remarkable outliers.

Around the smaller volcanos of Rum and Ardnamurchan the destruction of the basaltic plateaux has been carried still further, and only a few fragments in the island of Rum, with those of Eigg and Muck and that in Ardnamurchan, remain to tell of their former vast extent and thickness. In the cases of the island of Eigg and of the peninsula of Ardnamurchan it is clear that this work of destruction by denudation would have been carried much further but for the fact of the protection to the Miocene basalts afforded by the solid masses of newer lavas erupted in Pliocene times—those, namely, which form the lofty ridge of the Scur in the former case and the mountain-pass of Beinn Shiant in the latter.

Now the volcanic action which took place during the Tertiary epoch has operated in three different ways in effecting the preservation of relics of the Secondary strata in the Western Highlands.

First, by burying these strata under deposits of lava, the successive streams of which were in some cases piled upon one another to the depth of 2000 feet. By this means the destructive effects of denuding forces on the soft Mesozoic deposits has been arrested during the enormous periods required for the removal of these vast masses of lava.

Secondly, by entangling portions of the Secondary strata between sheets of igneous matter, intruded in a fluid condition into their midst, usually in planes coinciding approximately with those of the bedding of the sedimentary masses. As these intrusive sheets usually consist of rocks of highly crystalline character and intense hardness, they frequently display most remarkable powers of resistance to the denuding forces; and the patches of Secondary rock enclosed between them—which have often themselves been rendered less susceptible to disintegrating action through contact metamorphism—are preserved with them.

Thirdly, by enclosing fragments of the Secondary rocks after they were blown from eruptive vents in the piles of agglomerate and tuff constituting parts of the ancient Tertiary volcanic cones.

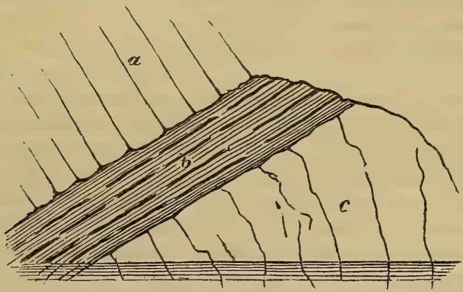
The frequency with which the traces of Secondary strata are found appearing from underneath the lava-cliffs of the great basaltic plateaux of the Hebrides is very remarkable. As in many of these instances, however, the beds in question are almost wholly concealed by taluses, while in others they are exposed to view only at dead low-water, and in some cases they must be examined during favourable concurrences of spring-tides with certain winds, their study is attended with great difficulties; but it is almost certain that, were we able to reach the base of the series of lavas at other points, we should find many more exposures of the Secondary strata. In short, it is clear that those great movements of subsidence which, as we have seen, have operated so powerfully in the Western Isles, have had the effect of placing many of the Secondary rocks far below the sea-level, and thus hopelessly out of reach of at least the present race of geologists.

The examples of the relations of the Secondary rocks of the Hebrides to the superincumbent lava-masses which we have already given will sufficiently illustrate the first of the three methods by which the Mesozoic relics have been preserved. Of the second case, that in which masses of the Secondary rocks have survived to the present time through being included between intrusive sheets of igneous rock, we have also many striking examples. On the east coast of the peninsula of Trotternish, in Skye, as was so well shown by Macculloch, the sheets of dolerite are found running along the planes of bedding of the Secondary strata for miles with the greatest regularity; so strikingly is this the case, indeed, that they might easily be mistaken for contemporaneous lavas, but for the fact that they occasionally cross the lines of stratification or send off dykes and veins into the enclosing beds, which exhibit signs of metamorphic action as well above as below the intrusive sheets. Between Loch Staffin and the Kilt rock, on that part of the coast of Skye, an intrusive sheet of dolerite, which is about 100 feet in thickness and remarkably columnar in character, is seen forced between and capping a series of interesting Secondary rocks, the preservation of which is clearly due to its presence and power of resisting denudation. At points a little further to the south, on the coast of Trotternish, as many as eight or nine intrusive sheets of dolerite may be traced traversing the Mesozoic strata in parallel planes. Occasionally, indeed, as is well seen near the north point of the island of Eigg, the intrusive sheets are so numerous and so close together that the included beds of Secondary rock become quite insignificant and subordinate to the igneous masses which have been thrust between and now enclose them.

But the most striking example of the kind which we are able to adduce is unquestionably that of the Shiant Isles, where fragments of the Secondary strata are seen to be entangled between two intrusive sheets of truly stupendous proportions. The uppermost of these is over 500 feet in thickness, and consists of excessively coarse dolerite passing into augitic gabbro, the whole having a grandly columnar structure, the columns having a diameter of 5 or 6 feet. Of the lower intrusive mass only the upper part is seen, and it does not exhibit the columnar structure in any thing like perfection. It is impossible for the geologist to look upon the grand cliff of the island of Garaveilan, with its façade of columns resting on a base of altered shale and sandstone and rising to a height of more than 50 feet—the whole constituting an object far surpassing Staffa, if not in regularity and grace, at all events in grandeur—without reflecting on the enormous amount of dislocation and crumpling of the surrounding rock-masses which must have been produced when this tremendous wedge of igneous material was forced into their midst. The igneous masses of the Shiant Isles were not improbably connected with a centre of volcanic activity in Tertiary times, of which every trace has been since removed by denudation, except these three small islets lying midway between the northern extremity of Skye and the Lewis.

The general relations of the volcanic rocks to the Mesozoic strata in the Shiant islands are exhibited in the accompanying section (fig. 6).

Fig. 6.—*Secondary Strata of Inferior-Oolite age entangled between two intrusive sheets of Dolerite, Garaveilan, Shiant Isles.*



a. Coarse dolerite, forming massive columns.
b. Inferior-Oolite shales and sandstones greatly altered.
c. Dolerite imperfectly columnar.

Of the third method by which relics of the Mesozoic period have sometimes been preserved—namely, the inclusion in volcanic agglomerates of fragments of Secondary rock torn from the sides of the vents and brought to the surface by explosive action—we have many examples, especially in the case of the island of Mull, some of which I have alluded to in a former paper. These fragments not unfrequently contain fossils, and thus, like the similarly ejected masses found in Vesuvius and other recent volcanos, furnish clear evidence of the nature of the age and character of the rocks through which the igneous vents have been opened and on which the volcanic cones have been piled up.

From this description of the various conditions under which the patches of Secondary strata have been preserved for our study, it will be clear that the work of investigating their age and their relations to one another, though full of promise, is, nevertheless, attended with very considerable difficulty.

The Secondary strata of the west coast of Scotland are found lying sometimes upon the Torridon Sandstone, at others upon the great gneissic series of the Highlands—now usually referred to the Silurian. Occasionally, as on the south side of the island of Mull, they may be observed resting directly upon the volcanic rocks and conglomerate beds of the Old Red Sandstone period; while in one very interesting case, that of the Innimore of Ardtornish referred to above, I have detected them reposing on strata of Carboniferous age. It is clear, from the unconformable relations of these Mesozoic strata to all the older series of rocks, that disturbances and denudation on the most enormous scale must have preceded their deposition.

Equally certain is it that very considerable subterranean movements and a vast amount of denuding action must have taken place in the area in question during the Mesozoic period itself. This is proved by the irregularities in thickness and the variations in the development of the different members of the Secondary series, and still more by the striking unconformities between certain of them. Thus, as we shall point out more fully hereafter, the Upper Cretaceous strata overlap all the older rocks, being seen to rest on the Middle Lias at Carsaig, the Lower Lias at Loch Aline, the Poikilitic at the Innimore of Ardtornish, and the Older Palæozoic at Gribun.

Except in a very few instances, such as those of Strath, Applecross, and Ardnamurchan, the Secondary rocks do not constitute any conspicuous areas capable of being represented upon geological maps; in the cases cited it is sufficiently manifest, too, that they are now only exposed at the surface, in consequence of the removal of superincumbent lava-masses by denudation. The determination of the relations of these isolated fragments of strata to one another by mapping their lines of outcrop is therefore altogether out of the question in most cases; and in the few in which it is at all practicable the amount of dislocation and igneous intrusion to which the strata have been subjected renders the task one of much difficulty and, at best, very considerable uncertainty.

Continuous sections of these rocks are also rare, and where they do exist, as on the east coast of Skye, are usually much interrupted, complicated, and obscured by the intrusion of sheets and dykes of igneous rocks among the strata. In the magnificent precipices of the east coast of Raasay it is true that we have a section of over 1000 feet in depth extending for a distance of several miles, one which is perhaps without a parallel for its magnitude and variety in the British Islands; but even here there is, unfortunately, a very serious drawback to the satisfaction felt by the geologist who studies this section; for its very magnitude militates against its value, since a very large portion of it is utterly inaccessible, and those parts which can be reached are much obscured by taluses. Even the smaller and more accessible sections of the Secondary rocks exposed beneath the basaltic cliffs of the Western Isles are also often, to a very great extent, covered and concealed by fallen masses of the harder igneous masses which have tumbled from above; and in such cases the best exhibition of the beds is often to be found in the reefs exposed along the shore at low water.

In addition to these hindrances to his study the geologist too frequently finds that the patches of Secondary rocks, even when reached, are capable of affording him very little information. Wherever, for example, these masses of Secondary rocks happen to be in close proximity to one or other of the great volcanic centres, as in Ardnamurchan and along the greater part of the south coast of Mull, the strata have been metamorphosed almost beyond recognition; they are in such cases found to have assumed a more or less crystalline character, and their fossils have been often to a great extent and sometimes completely obliterated. It is, indeed, only at considerable distances from the centres of igneous activity that the geologist has the smallest chance of finding these sedimentary masses in a sufficiently unaltered condition to supply him with useful records of the periods during which they were deposited; and even in some cases where they are at a sufficient distance from the great volcanic centres to have escaped in the first instance from metamorphic action, subsequent smaller outbursts, which have taken place in close proximity to them, may have produced injurious effects on their fossil contents, as is well seen beneath Beinn Shiant.

Among the difficulties caused by the complication of stratified deposits with intrusive sheets we may mention that of determining their exact thickness, the task being in some cases, indeed, as in the north of Eigg and in Trotternish, rendered absolutely hopeless in consequence of the number and capricious behaviour of the intrusive masses lying in their midst.

Of the wonderful changes at times effected in the character of the sedimentary strata, of the complex intervening of bedded and intrusive masses, such as is seen in Strathaird, Ardnamurchan, Rum, and Mull—where the bulk of the intrusive sheets and dykes taken collectively sometimes far exceeds that of the older stratified masses among which they have been forced—it is impossible to convey any adequate idea to those who have not had an opportunity of visiting the district. Macculloch's drawings of the dykes of Strathaird * and of the wonderful section of Stronbeg in Ardnamurchan† may perhaps give some faint idea of the strangeness, complexity, and interest of the phenomena in question.

But in spite of the numerous difficulties, the serious obstacles, and the trying disappointments which the investigator of the Secondary strata of the Western Isles must be prepared to encounter in his task of detecting and studying these isolated patches of fossiliferous rock, of reasoning concerning their relations, and of combining these scattered relics of a long series of epochs in the world's past history, he finds most ample compensation in the absorbing interest of the subject; nor will he begrudge any labour or pains when he reflects upon the importance of these singularly preserved fragments of geological evidence in enabling us to reconstruct the physical features of this portion of the globe during long past periods, and to unravel the complicated series of changes which the district now forming the Highlands of Scotland has undergone in the past. I cannot, indeed, conceive of a work more delightful to any one who has felt the least touch of the enthusiasm of research than that of seeking for and piecing together these torn, blotted, and almost utterly defaced pages of the geological record, and weaving from them a connected story.

* 'Western Isles of Scotland.' Atlas, pl. xiv. fig. 5, and pl. xvi. fig. 1.

† *Ibid.* pl. xxxiii. fig. 1.

IV. General Characters and Succession of the Secondary Strata of the Western Highlands.

In describing the Mesozoic rocks of the Eastern Highlands, we had occasion to refer again and again to the freqency with which deposits of marine origin alternate with others that exhibit clear evidence of having been accumulated under *estuarine* conditions. As we have already shown, this alternation of marine and estuarine strata constitutes the most salient and striking feature throughout the whole series of Secondary formations in Sutherland and on the east coast; and in the equivalent deposits on the western coasts and islands, the same phenomenon, if exhibited in a less marked degree, is nevertheless sufficiently common to impart to these strata characters by which they are strikingly distinguished from most of their English representatives.

Thus we find in the Mesozoic series of the Western Highlands that there occur in the Infralias beds in some localities a mass of sandstones with thin coal-seams; while the whole of the formations included between the *Parkinsoni*-beds of the Inferior Oolite and the middle portion of the Oxfordian are represented over a considerable area by a series of estuarine deposits, which probably attain in places to a thickness little short of 1000 feet. Even where distinct evidences of estuarine conditions are wanting in the Hebridean Jurassic strata, the deposits are clearly, as a general rule, of more littoral character than their equivalents in England—beds of conglomerates and other indications of the proximity of a shore-line making their appearance at a great many different horizons in the series.

We have pointed out the existence among the Jurassic deposits of the eastern coast of Scotland of two distinct types of strata of estuarine origin—one *argillaceous* or *calcareo-argillaceous* in composition, and resembling the Purbeck and Punfield series in the south; and the other mainly *arenaceous* in composition, and resembling portions of the English Hastings sand and Carboniferous formations. So strikingly, indeed, do the former class of strata—with their bands of limestone made up of *Cyclas*, *Cyrena*, or *Paludina*, their laminated shales crowded with Cyprids, their thick masses of dwarfed oysters ("cinder-beds"), and their seams of fibrous carbonate of lime ("beef- and bacon-beds")—resemble the series of deposits found at the base and summit respectively of the great English Wealden formation, that it is by no means surprising that, before their relations to the marine beds were made out, Murchison should have supposed that he had detected veritable Wealden deposits in the Western Isles.

But in the case of the Mesozoic series in the West of Scotland we find evidences of a still more interesting character, namely, that the tendency to a recurrence of estuarine conditions during the whole of the Jurassic period was continued all through the Upper Cretaceous. Although, as I have pointed out in my former paper, there is strong evidence that considerable patches of Cretaceous strata had escaped removal by denuding forces up to so recent a period as the Glacial epoch, yet we have at the present time no certain evidence of the existence *in situ* of any deposits of that age in the Eastern Highlands. In the Western Highlands, however, I have been so fortunate as to detect such evidences; and they enable us to arrive at a number of conclusions concerning the physical conditions prevailing in the area in question during the Cretaceous period that are of the most striking significance and the highest interest at the present time.

In the west of Scotland, as in the north of Ireland, the lowest Cretaceous strata exposed are of Cenomanian (Upper Greensand) age, and, as in the latter district, they are of marine origin. Above these marine beds, however, there occurs a series of sandstones containing thin coal-seams and other evidences of the prevalence of estuarine conditions; and these are in turn covered by a singular marine representative of the highest beds of the English Chalk—the Zone of *Belemnitella mucronata*. Finally, the second series of marine beds is seen in places to be covered by other estuarine and coal-bearing strata, which may represent the highest members of the Cretaceous (the Maestricht, Faxoe, and Meudon beds), or may be intermediate in age between the Cretaceous and Tertiary, or, lastly, may constitute the base of the great Tertiary series of rocks in the Highlands.

This remarkable series of alternating marine and estuarine strata of Upper Cretaceous age—so different in character from the deep-sea representatives of the same formations in the other parts of our islands—is unfortunately only very imperfectly seen at a few not very accessible points; and they moreover make their appearance in such a manner from beneath the vast and overwhelming masses of Miocene basalts as to afford but scanty facilities for their study and for the collection of their fossils; but the fact of the existence of such beds in the extreme north-western part of our archipelago, especially in face of the great development of estuarine Cretaceous strata on the North-American continent, is one of the very highest interest. Nor is that interest lessened by the fact that we find in the same area proof of the presence of a Cretaceous shore-line in the beds of coarse conglomerate into which the strata in question are sometimes found to graduate.

The Poikilitic strata of the Western Highlands, though not yet proved to be fossiliferous, like their representatives in the east (the reptiliferous sandstones of Elgin, &c.), are by no means destitute of interest; and the circumstance that while, on the one hand, they can be shown to be distinctly superposed on rocks containing undoubted Carboniferous plants, on the other they are conformably overlain by Infraliassic strata, is of the highest importance in its bearing on the long and vexed controversy concerning the age of the equivalent strata in the Eastern Highlands.

Although the different members of the Mesozoic formations in the Western Isles exhibit, as is so frequently the case with strata of littoral and estuarine origin, very numerous and rapid changes in thickness and character within comparatively short distances, yet when all the evidence is pieced together by the aid of the palæontological key it is found that this portion of the British Islands must at one time have been covered with an enormous thickness of strata, intermediate in age between the Carboniferous and the Eocene. This thick mass of strata, which in places attained probably to a vertical thickness little, if any thing, short of a mile, was represented by the following members, here shown in a tabular form, with their maximum thicknesses :—

TABLE *showing the Succession of the Mesozoic Strata in the Western Highlands.*

		Maximum thickness.
	Miocene Volcanic and Inter-volcanic rocks.	feet.
	UNCONFORMITY.	
CRETACEOUS	1. Estuarine clays and sands, with coal	20+
	2. White chalk with flints (Zone of *Belemnitella mucronata*)	10+
	3. Estuarine sandstones, with coal	100
	4. Upper-Greensand beds	60
	UNCONFORMITY.	
OOLITIC	5. Oxford Clay	?
	6. Great estuarine series	1000
	7. Lower Oolite	400
LIASSIC	8. Upper Lias	100
	9. Middle Lias	500
	10. Lower Lias	400
	11. Infra Lias	200
POIKILITIC	12. Conglomerates, sandstones, marls, and limestones	1000+
	UNCONFORMITY?	
CARBONIFEROUS.	Sandstones, shales, and coals.	
	UNCONFORMITY.	
OLDER PALÆOZOIC?	Gneiss rocks and Torridon Sandstones.	

It will be seen from the above Table that while the Poikilitic, the Liassic, the Oolitic, and Upper Cretaceous systems are all represented by deposits of very considerable thickness, several other members of the Mesozoic series have not as yet been detected on the west coast of Scotland. The principal formations found to be thus unrepresented there are the Upper Oolite and the Neocomian.

But I would ask the reader to call to mind the evidences, which I have already laid before this Society in a former communication, that the Upper Oolites are represented in the Eastern Highlands by deposits of great importance (probably not less than 1000 feet in thickness), and that there are some grounds for the inference that beds of

Neocomian age were likewise deposited in the same area, and at the same time to remember the evidence which there is of such enormous denudation having swept the district again and again during successive geological epochs; let him, too, reflect on the fact that beds deposited during the period in question would have the worst possible chance of surviving to the present day, in consequence of that wide-spread upheaval and erosion which preceded the Upper Cretaceous epoch; and keeping all these considerations before his mind, he will certainly hesitate before accepting the negative evidence in the case as final, and concluding from the absence now of any discoverable traces of the Upper Oolitic and Neocomian formations that deposition was not going on in any portion of this area during the periods in question.

On the enormous amount of denudation which must have taken place during the latter half of the Tertiary period, I have already dwelt in the earlier portion of this paper. In a former communication I showed how vast were the results effected in the removal of great thicknesses of rock during the earlier portions of the Tertiary period, before and during the long succession of eruptions from the great Hebridean volcanos; and now I must touch briefly on the great destruction of stratified masses which must have occurred in the period preceding the formation of the Cenomanian strata. The great unconformity between the Upper Cretaceous and all the older deposits on which it is found resting is a very striking feature both in the south of England, the Yorkshire area, and the north-east of Ireland; more than this, it is, as Professor Suess of Vienna has so well pointed out*, equally well-marked in the Alps and almost everywhere within the European area. But this remarkable unconformity and overlap is nowhere better exhibited than among the exposures of the Secondary strata in the Western Highlands and Hebrides, where the Scottish Upper Greensand is seen overlapping all the older formations and resting sometimes on the Jurassic, at others on the Poikilitic, and others, again, on the Older Palæozoic gneissic rocks. That this unconformity and overlap has been brought about by grand and widespread subterranean movements—elevation, denudation, and subsidence succeeding one another during long periods—no geologist can for a moment doubt. This being the case, we are certainly, as I have already hinted, prepared for, and the less surprised at, the absence of those members of the Mesozoic series that would be deposited immediately before the incidence of this epoch of change, and would consequently be the first to suffer during its revolutions. And in a district where only minute patches of older deposits have escaped destruction in consequence of a concurrence of accidents (of such remarkable character in themselves and occurring in such singular combinations), it would be idle for the geological interpreter to express surprise, however keen may be the regret he feels when he finds certain chapters of the record altogether missing.

* See his 'Entstehung der Alpen.' Vienna, 1876.

V. Description of the Secondary Strata and Associated Formations in the Western Highlands.

I will now proceed to give an account of the various formations which are found represented in the singular patches of strata that lie between the old gneiss rocks and Torridon Sandstones of the Highlands on the one hand, and the great masses of superimposed Tertiary lavas on the other. The Carboniferous, Poikilitic, and Cretaceous systems, as here represented, will demand detailed description at my hands, as they have not before been noticed. With respect to the Jurassic strata, however, I shall only treat generally of those accessible and tolerably well known sections which have been illustrated by the writings of other geologists; and wherever it is possible to do so, I shall simply refer to lists of fossils already published in this Journal, reserving to myself, however, more latitude in describing the sections hitherto noticed but imperfectly or not at all, and seeking especially to illustrate the changes which the several formations are found to undergo as they are traced over considerable areas.

Even when thus limited, however, I find that the present part of this memoir will extend to a somewhat excessive length, and I am compelled to relinquish the intention I once held of describing, either by myself or with the assistance of others, the new forms of life which I have obtained during my studies. Some of these new forms are undoubtedly of very considerable interest; but it is desirable that they should be described in monographs treating especially of the life-groups to which they belong rather than in connexion with a memoir devoted to the discussion of problems like those with which we are at present concerned.

A. The Carboniferous System.

Very interesting, indeed, as affording a well-characterized base on which the remarkable series of Mesozoic strata which we are describing reposes, is the mass of Carboniferous rocks which I had the good fortune to discover in Morvern in the year 1877. Like the Secondary rocks which are superimposed upon them, these Carboniferous deposits are a mere vestige of a doubtlessly once widely spread formation which, as the consequence of a concurrence of remarkable accidents, has escaped total destruction through denudation. The patch now remaining for our study is excessively small, extending only for a few hundreds of yards along the shore—on the east being suddenly cut off by a great fault with a throw of something like 2000 feet, and on the west being overlapped and concealed by the superincumbent Poikilitic strata.

What is still more unfortunate is, that these remarkably isolated Carboniferous beds are exposed only in a series of tangle-covered reefs in front of the wild ravine of the Innimore of Ardtornish, and these are uncovered by the sea only at low water during spring-tides. Hence the geologist has to wait for a favourable concurrence of suitable low tides with an off-shore wind in order to be able even to approach the object of his quest.

Small in extent, however, as is this outlying patch, and difficult of access, it fortunately yields to us most unmistakable and satisfactory evidence of its age and characters. I have several times succeeded in reaching the spot when the conditions were favourable for its examination—sometimes by traversing the face of the grand basaltic cliffs of Ardtornish, at other times by means of a boat from Loch Aline or the opposite shore of Mull. During the last season I had the pleasure of visiting the locality in company with Dr. Taylor Smith, during very stormy weather, it is true, but at a time when the other conditions were particularly favourable for the study of the rocks.

These beds of the Innimore of Ardtornish consist of somewhat coarse white sandstones, and of fine-grained highly micaceous sandstones of a very dark tint, passing occasionally into shales. Both the coarse-grained and the fine-grained rocks are crowded with plant-remains, which in the former exist as hollow casts, and in the latter retain their carbonaceous matter. Occasional thin and imperfect seams of coal occur, and the agreement in physical characters of this most northern patch of Carboniferous strata with the strata of the same age in other parts of our islands is most complete and striking.

Fortunately, too, the palæontological evidence as to their position in the geological series is of the most satisfactory character. The plant-remains, though abundant, are seldom sufficiently well preserved for specific determination. Among the forms which I have been able to detect as occurring there are:—

Lepidodendron aculeatum, *Presl.*
Calamites Suckowii, *Brongn.*
—— Cistii, *Brongn.*
Sigillaria Saullii, *Brongn.*
Stigmaria.

The only specimen of *Lepidodendron* which I have been able to obtain is an example more than a foot in diameter. This and the species of *Calamites* afforded the most satisfactory evidence concerning the age of the strata.

I may add that my recognition of the age of these deposits is supported by the opinion of the most competent palæophytologists from the examination of the specimens obtained. Sir Charles Bunbury, to whom my earliest specimens were sent by the late Sir Charles Lyell, and Mr. Carruthers and Professor Morris, who have examined a somewhat larger series, all agree that it is impossible to refer the plant-remains to any other horizon than the Carboniferous.

This series of Carboniferous strata, where best exposed, cannot exceed 40 or 50 feet in thickness; its relations, however, are unfortunately by no means very clearly exhibited. That it reposes directly upon the gneissic rocks of the district there is every reason for believing; for these rocks compose the islands of Ridire and the Grey-Island group, which rise above the waters of the Sound of Mull between the Innimore of Ardtornish and the opposite shore of Mull; and that it is unconformably superposed on these old rocks there can be little room for doubting. We have already mentioned that the Poikilitic beds of the reefs to the west and in the cliff-section of the Ardtornish ravine clearly lie above the Carboniferous strata; but as to the question whether an unconformity exists between these two series, I have altogether failed in obtaining satisfactory and conclusive evidence, so imperfect are the exposures at this locality.

The wonderful interest attaching to these Carboniferous strata—forming a patch so minute in dimensions and so isolated in position—arises from the fact that they afford evidence of the extension of strata of the Carboniferous age into areas in which they were formerly unknown and were believed never to have been deposited. Sir Roderick Murchison and other authors have argued that the absence of Carboniferous rocks in the Scottish Highlands must be accepted as proof that such strata were never deposited in the area, and that the rocks now forming that mountain district constituted at a period so early as the Carboniferous a continuous land-surface. But here, as in so many other cases in the same district, we find a most striking illustration of the effects produced by denuding agents during past geological epochs, and a warning as to the necessity for exercising the greatest caution in drawing deductions from the absence of strata in a given area as to whether they were ever deposited in it.

B. The Poikilitic System.

To the indefatigable and sagacious Macculloch we are indebted for first pointing out that there exists in the Western Highlands at Gruinard Bay evidence of a series of Red Sandstone strata unconformably overlying, and therefore of far later date than, the great masses of Red Sandstone (Torridon Sandstones) which constitute a grand and widely spread formation in the north-western part of the British archipelago. Macculloch, Murchison, Sedgwick, and Nicol, assuming (as was universally done by the earliest students of Highland geology) that the Torridon Sandstone represented the "Old Red," saw that the most probable position to assign to the unconformable strata would be that of the "New Red." Prof. Nicol has added many new and exact details concerning these interesting beds in a paper read before this Society in 1857*.

But it is evident that the admission, now very generally made, that the Torridon Sandstones are of older date than the Old Red, once more places the question of the age of the overlying deposits in a state of uncertainty.

Other deposits of similar character to the strata of Gruinard Bay have been referred to as existing in Raasay, and by Dr. Bryce were thought to be possibly of Rhaetic age.

These and a great number of scattered masses of conglomerate, sandstone, marl, and concretionary limestone I have now been able

* Quart. Journ. Geol. Soc. vol. xiv. p. 167.

to correlate with one another, to show that they constitute portions isolated by denudation of a once widely spread formation which attained to a very great thickness, certainly exceeding 1000 feet, and to demonstrate that this formation rests upon Carboniferous, and overlaps older strata, and is covered conformably by the strata of Infra-lias, Lias, and Oolite age. Further, it has become manifest to me during my study of the district, that the strata in question present the closest agreement in physical characters with deposits on the eastern side of Scotland which have been rendered famous by the controversy concerning the vertebrate remains which they contain: I refer to the Reptiliferous Sandstone of Elgin and the accompanying Stotfield rock. Under all the circumstances of the case we can have little hesitation in referring all the strata in question, which have so wide a distribution in Sutherland, Elgin, Ross, Argyllshire, and in a number of the Hebridean islands, to that series of formations which in our islands intervenes between the Carboniferous and Jurassic systems, and for which the name of Poikilitic has been suggested by Conybeare and revived by Huxley. The Poikilitic strata of the Highlands present striking resemblances, in their physical characters, their stratigraphical relations, and their fossil contents, to the beds of the same age in the more southern districts of the British Islands.

These Poikilitic strata of the Western Highlands consist of a very variable series of deposits—breccias and conglomerates alternating with variegated sandstones, clays, and impure concretionary limestones. The conglomerates are, in some instances, found to be composed of perfectly well-rounded pebbles; more frequently, however, the fragments of which they are made up are subangular; and occasionally they retain their unworn edges and angles, and the rock thus passes into breccia. The associated sandstones are usually coarse-grained, and show a tendency to become, in places, conglomeratic, while false-bedding, ripple-marked surfaces, and clay-galls are phenomena very frequently exhibited by them. The clays, which are often more or less sandy, are usually of red, green, or mottled tints, and strikingly resemble the so-called "marls" of the English Poikilitic. The limestones are usually very impure in composition—sometimes argillaceous, at others sandy in character; and they are not unfrequently associated with, and pass into, a rock of siliceous composition.

The materials forming the breccias, conglomerates, and coarser sandstones have evidently been derived directly from the rocks on which the Poikilitic strata at the particular locality repose—usually either the Torridon Sandstone or some member of the great gneissic series of the Highlands. One feature which the Poikilitic conglomerates and sandstones all present, and which serves to distinguish them from all other similar strata in the Highlands, is the abundance of calcareous material which enters into their composition. Not only do fragments of compact limestone (derived probably from the Durness or other calcareous beds now wholly removed by denudation) abound in these strata, but their particles are frequently united by a cement of carbonate of lime, the sandstones thus passing into calcarous grits, and some of the clays becoming true marls. The beds are frequently found to be traversed in all directions by innumerable veins of Calcspar.

That the limestones are of chemical and not organic origin is evident both in the case of the beds in the Western Highlands and in that of the equivalent "cherty-rock of Stotfield," with which they so closely agree in character. From a study of all the features of these Poikilitic strata of the Highlands, I am inclined to accept the suggestion first made by Mr. Godwin-Austen, and afterwards supported by Prof. Ramsay, with regard to their English equivalents—namely, that they have been accumulated in inland lakes and not in the open ocean. In the Poikilitic strata of the island of Inch Kenneth some irregular beds and veins of gypsum occur; and these, though of no considerable thickness or importance, constitute another point of resemblance between the Highland strata and their equivalents in the southern part of the kingdom. Beds of rock-salt, it is true, do not occur in them; but in almost every other respect the resemblance between the Poikilitic strata in the northern and southern areas of Britain is of the most marked character.

The Poikilitic Series of the Western Highlands varies greatly in the thickness and order of succession of its beds. While at Gruinard Bay it certainly exceeds 1000 feet, in Raasay it is probably less than one half that thickness, and at Lussay, in Skye, it is reduced to a few feet only. At Ru-Geur, in Sleat, the formation shows signs of regaining somewhat of its thickness and importance, which characters it certainly retains in Ardnamurchan and some points in Mull, while in Morvern it is probably not less than 1200 feet thick in some places, whilst in others it is reduced to comparative insignificance. As a general rule, the breccias and conglomerates prevail in the lower parts of the series, sandstones, clays, and limestones in the upper; but everywhere the succession of beds is most irregular and inconstant, thick and important members thinning out and disappearing or totally changing their characters within very short distances.

None of the Poikilitic rocks of the west of Scotland have as yet yielded fossils capable of determination; with the exception, indeed, of a few imperfect casts of bivalve shells (*Cyrena*?) which I found some years ago in a quarry at Ardtornish Towers, I know of no traces of organic remains occurring in the beds. In spite of this absence of fossils, however, their position in the geological series is placed beyond doubt by the following facts:—

(1) They conformably underlie the Infralias strata of the district.

(2) They unconformably overlie and overlap the Carboniferous and other Palæozoic rocks.

(3) They agree most strikingly in character with strata on the east coast of Scotland, of which the age has been demonstrated by a concurrence of palæontological and stratigraphical evidence.

Whether particular portions of the strata should be referred to the formations which are elsewhere relegated to the Permian, Trias, and Rhætic respectively, we are at present wholly unable to determine.

In addition to these general remarks on the stratigraphical relations of the Poikilitic strata of the Western Highlands, it is only necessary to add that at Gruinard Bay, in Raasay, and in Sleat these strata rest on the Torridon Sandstones; in Strath, Ardnamurchan, Inch Kenneth, Gribun, and round Loch Arienas on the old gneissic rocks of the county; and at the Innimore of Ardtornish upon Carboniferous deposits. At Gruinard Bay they are not seen to be covered by any younger formation except the glacial deposit; but at Raasay, Sleat, and Ardnamurchan they are followed by highly fossiliferous Infralias strata, apparently everywhere in perfectly conformable succession; while at Sleat, Inch Kenneth, Gribun, Loch Aline, and in the remarkable outliers of Morvern they are unconformably overlain, sometimes by the Upper Cretaceous strata, and at others by the great masses of Tertiary lava.

After this general account of the formation in question, it will only be necessary to add some remarks on the peculiarities presented by the different sections of its beds, which occur over an area stretching nearly 120 miles in length, from Gruinard Bay in the north to Gribun in the south.

At Gruinard Bay the Poikilitic strata are well exhibited in a succession of sea-cliff and and shore-reef sections, stretching for a distance of over three miles. Inland they are wholly covered and concealed by boulder-clay and peat-mosses. As already pointed out, they owe their position and preservation to the action of grand faults of certainly vast but indeterminate amount of throw, by which they are brought far below their original position and troughed into the heart of the Torridon-sandstone masses. Several parallel faults traverse this down-dropped relic of strata; and its beds show many signs of the subterranean disturbances to which they have been subjected* (see the section, fig. 1, p. 671).

The unconformable relations of these Poikilitic deposits to the Torridon sandstones, on which they rest, has been dwelt upon and well illustrated by both Macculloch† and Nicol‡, who have accomplished so much in unearthing the secrets of Highland geology. These unconformable relations are of the most striking and unmistakable character—the Poikilitic beds dipping generally W. or N.W., while the underlying Torridon sandstones lie at very high angles, with varying strike, and are sometimes vertical and at others contorted. The little sketch of a boat-house given by Prof. Nicol, the walls of which are formed of Torridon sandstone, and the roof of Poikilitic strata, serves to give some idea of the very striking appearances that may be witnessed along this interesting shore. The section I have already given shows how the Poikilitic strata are bent into gentle folds, and are faulted and interrupted along the shores of Gruinard Bay.

In company with my friend Dr. Taylor Smith I estimated the thickness and succession of the Poikilitic beds as exposed in a continuous series of sections between the salmon-house west of Sands,

* 'Western Isles of Scotland', Atlasplate xxxii. fig. 8.
† Quart. Journ. Geol. Soc. vol. xiv. p. 168.
‡ *Ibid.* vol. xiv. (1858), p. 168.

and the farmhouse of Udrigle, where the upward succession is abruptly terminated by the western fault. After making every possible reduction, and checking our estimates of the breadth of outcrop of the several members by means of the large and accurate Admiralty Chart, I feel justified in stating the following to be the succession and approximate thicknesses of the strata at this locality. The section given proceeds from the base upwards.

(1) Coarse breccia-conglomerates of subangular fragments of sandstone, quartzite, limestone, &c., alternating with red and mottled, false-bedded, often argillaceous sandstones, with a few pebbles scattered through their midst, the whole being traversed by many veins of white calc-spar; where in contact with the underlying Torridon Sandstones the larger fragments are all evidently derived from that formation, and are sometimes almost perfectly angular and of considerable dimensions. In the lower part of this series the breccia-conglomerates certainly preponderate over the sandstones; but in the higher parts the former are found gradually to become less and less prominent, and towards the summit only occasional bands of conglomerate occur in the midst of thick masses of argillaceous strata. This series is certainly of very great thickness, the lowest possible estimate being 500 feet.

(2) The argillaceous sandstones of the lowest member of the series graduate upwards almost insensibly into thick masses of red and variegated clays and marls, which in places are very sandy in character. These very strikingly resemble portions of the English Keuper, and only occasionally contain thin sandstone bands, which are sometimes conglomeratic. Some beds of sandstone of a sea-green colour, and irregular bands of impure concretionary limestone, also occur in this part of the section. In its upper part this member of the Poikilitic exhibits a preponderance of arenaceous over argillaceous strata, and conglomerates become more common; its thickness is certainly over 200 feet.

(3) Soft reddish argillaceous and sandy beds in alternating succession, with some bands of white and greenish sandstone and grit, which, on account of their hardness and power of resisting atmospheric denudation, often stand out very prominently in the cliff-section. Conglomeratic beds are exceedingly rare in this part of the series, which certainly exceeds 200 feet in thickness up to the point where the upward succession is abruptly terminated by the great fault.

These three divisions of the Poikilitic, which, however, are not in any way sharply divided from one another, as seen at Gruinard Bay, have each their analogues, which seem to follow one another in somewhat corresponding order, at several other localities where the same strata are exposed in the Western Highlands.

The next point at which, in proceeding southwards from Gruinard Bay, we detect traces of the Poikilitic beds, is in the island of Raasay. Here there occur two very interesting sections. At one of these, situated at the point called Ru-na-Leac, the highest beds of the formation are seen unconformably underlying all that series of Jurassic strata which is so finely exposed in the magnificent precipices of Hallaig and Screpidale. The strata which are here seen in passing downwards from the Infralias rocks that lie immediately and conformably above them are as follows:—

(1) White, reddish, mottled, and ferruginous sandstones, exhibiting much false bedding, and becoming conglomeratic in places. These beds contain many limestone fragments, and in places much calcareous matter in their matrix. Their thickness is at least 80 feet.

(2) Red and mottled clays and marls, often very sandy, and sometimes conglomeratic. These beds pass in places into true sandstones and conglomerates, and contain some bands of concretionary limestone. Thickness 60 feet.

(3) Conglomerates (formed of rounded or subangular fragments of white and purple quartzite, of Torridon Sandstone, and of compact or subcrystalline limestone) alternating with irregular lenticular beds of coarse micaceous sandstone, into which the conglomerates often insensibly graduate. These beds exhibit reddish and greenish tints, and closely resemble in character the lowest beds of Gruinard Bay. Thickness seen 60 feet.

This series of strata is thrown against beds of Middle-Lias age by the great Hallaig fault, which has a throw of at least 700 feet (see fig. 2, p. 671). It is probable that these 200 feet of strata at Ru-na-Leac comprise nearly the whole section of the Poikilitic in this island; but as the Torridon Sandstones have not been seen to make their appearance from beneath the conglomerates even at the lowest tides, it is impossible to speak with certainty upon the question.

At a point called Ayre, in the same island of Raasay, and lying south of Ru-na-Leac, there is found a conglomerate resting unconformably upon the Torridon Sandstone, and largely made up of its fragments, but with the addition of some pebbles of limestone; and this, there can scarcely be the smallest doubt, belongs to the base of the series, all the upper beds having been removed by denudation.

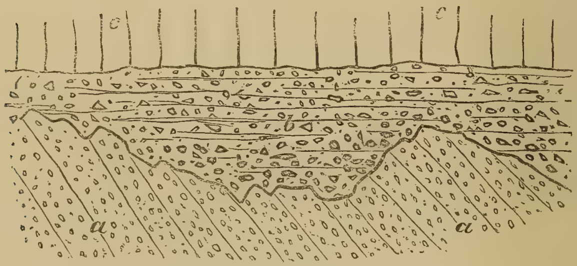
At Castel Brochel, in Raasay, several miles to the north of Ru-na-Leac, another mass of conglomerate makes its appearance upon a projecting headland, on which the famous and singularly situated old Highland stronghold is perched. As the conglomerate in question, however, is very different in many of its characters from the Poikilitic beds of the area, especially being distinguished from them by containing no limestone fragments as well as in its general aspect, and as, moreover, the relations of the isolated patch of conglomerate are of a doubtful and indeterminate character, I find no grounds on which to assign it either to the Poikilitic or to any other part of the Secondary series of strata.

The Poikilitic beds in Raasay appear to have a much less thickness than those of Gruinard Bay; and when we proceed southward into Skye that thickness is found still further diminished, and the formation in question is thus reduced to a merely rudimentary condition. Beds of pebbles, constituting a thin conglomerate band, have been detected at several points at the junction of the Jurassic strata and the Torridon Sandstone at Strath in Skye. In the coast-section at Lussay there is evidently an interval between the Jurassic rocks and the Torridon Sandstones that unconformably underlie them; but the strata in this interval are only very imperfectly exposed even at the lowest spring-tides. So far as I have been able to determine, after several investigations of this locality, the downward succession of beds below the Infralias seems to be as follows:—

(1) Thin band of sandy clay containing irregular calcareous concretions.
(2) Variegated marls and clays (red, greenish, and mottled).

These strata are very thin; and it is probable that they are underlain by some conglomerate beds, which, however, are wholly concealed in the coast-section.

Fig. 7.—*Section of Poikilitic Beds at Ru Geur, near the Southern extremity of Sleat, Skye.*



a. Torridon Sandstones. *b.* Poikilitic strata.
c. Phonolitic rock (columnar).

In the singularly preserved patch of Ru Geur, in Sleat, previously referred to, a very remarkable relic of the Poikilitic series is found interposed between a foundation of Torridon Sandstone and a capping of finely columnar Tertiary phonolite (see fig. 7). Not more than 15 or 20 feet of the beds in question are here exposed; but so similar is the rudely stratified mass, consisting of alternating lenticular beds of fine and coarse conglomerates, composed mainly of Torridon Sandstone, but with a fair percentage of quartzite and limestone pebbles and a tolerable quantity of calcareous matter in its matrix, that there is little room for doubting that these strata should be referred by us to the Poikilitic period.

In going still farther southwards it is in Ardnamurchan that we find the next exposures of the Poikilitic series; and here they have evidently reacquired some of the thickness and importance which, as we have seen, they had lost in Skye.

At Surdil, on the north coast of Ardnamurchan, we find that the beds of highly contorted gneiss have their eroded hollows filled by masses of angular fragments of the same rock; and these are covered by conglomerates and sandstones, above which appear the Infralias limestones with well-marked fossils. Although it is certain that at Surdil the Poikilitic beds are present and of considerable thickness, yet so broken up are the strata by faults, so traversed and interrupted are they by igneous dykes and sheets, and so masked are their characters by metamorphic action, that it is impossible to make out any very clear order of succession among the beds or to estimate their total thickness with any approach to accuracy.

The same remark applies almost equally to the section on the south side of the Ardnamurchan peninsula, to the east of Mingary Castle. Here it is evident that beds of breccia and conglomerate, made up of gneiss, quartzite, and limestone pebbles, and often having a calcareous matrix, are interposed between the old gneiss rocks and the here greatly metamorphosed Infralias limestones. But neither in the coast-section nor in the exposures of the same strata inland, in the interval between them is it possible to obtain any satisfactory order of succession or correlation of beds, where all have been subjected to such violent subterranean movements, igneous intrusion, and profound metamorphism in consequence of the proximity of the great Miocene volcanic centre of Ardnamurchan, and the long subsequent action of the far inferior but by no means insignificant igneous extrusions of Beinn Shiant.

In Morvern the Poikilitic strata evidently attain in places considerable thickness and importance; but both the order of succession of beds and the degree of development of the whole mass exhibit most wonderful diversities within very short distances.

Around Loch Arienas, under three of the great outlying patches of basalt that lie on the north side of that lake and the arm of the sea called Loch Teachdaish, and again near the head of Loch Aline and at the base of the cliffs of Ardtornish, we everywhere find the variegated sandstones and marls, the calcareo-siliceous rocks, the coarse conglomerates and breccias, so characteristic of this series of deposits. At Ardtornish Towers is a rather deep quarry in the coarse and conglomeratic sandstone of pink and greenish tint, almost wholly made up of quartz pebbles. This quarry is remarkable as having afforded the only traces of fossils of the Hebridean Poikilitic strata; and these are, as we have seen, of the most imperfect character. The conglomeratic sandstones of Ardtornish Towers, of which some 50 or 60 feet are exposed, though the bottom is not reached, are covered by beds of red and white clays and sands, with masses and layers of concretionary limestone, strikingly similar in character to the cherty rock of Stotfield.

It would be of little service to give details of the numerous small exposures of these very variable strata. Suffice it to say that everywhere in Morvern we find the general order of succession to be (from above downwards):—

(1) Red, green, grey, and variegated sands and sandy marls.
(2) Concretionary limestones, sometimes of considerable thickness.
(3) Red marls and some sandy beds.
(4) Coarse conglomerates, grits, and sandstones, with breccias at the base.

We may further remark that the thickness of these several members is most inconstant, the total varying from a few feet only in Beinn-y-Hattan to about 200 feet near Kinloch Aline, and 400 or 500 feet at the Innimore of Ardtornish.

Wherever the Poikilitic series is complete in Morvern it is covered conformably by the Infralias limestones; but at many points its members are seen to be overlapped by the Cretaceous beds.

It is very characteristic of the Poikilitic beds to vary wonderfully in thickness and character within short distances. Nowhere is this more strikingly illustrated than in the two opposite sides of the Sound of Mull. On the Morvern side of the Sound, at the Innimore of Ardtornish, the series is some 400 or 500 feet thick; but on the Mull side, at Craignure (Auchnacroish), it is found to be reduced to an insignificant amount. The strata at this latter locality are greatly metamorphosed, the sandstone pebbles being converted into quartzite and the limestone into marble, and the colours of both frequently discharged. The igneous intrusions are so numerous and complicated that the exact thickness and succession of beds in it is as difficult to estimate as in the analogous case of Ardnamurchan. At the very base of the series, and lying directly on the older rocks, is a breccia composed of angular fragments of gneiss and quartzite; but this can only be seen at low water during spring-tides.

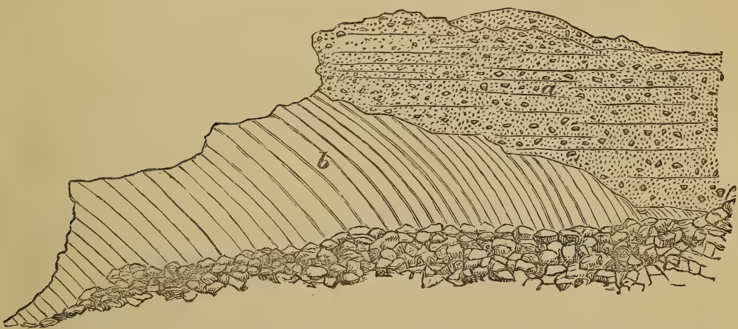
In Duart Bay, and at some other points along the west side of the Sound of Mull, we find more or less distinct traces of the beds of the Poikilitic series. In some of these cases the exposures are so small, and in others the beds have undergone such an amount of metamorphism, that it would be idle to attempt to do more than chronicle their existence. In some cases, as opposite to Calla Island and below the precipitous cliffs of Toum Peroch, there are strata which, in their isolated position and their altered condition, it is impossible to state absolutely to belong to the Poikilitic, though perhaps the balance of evidence is in favour of such a determination. The consideration of the age of these doubtful deposits need not, however, detain us further.

The last point towards the south where the Poikilitic strata are seen is in the small island of Inch Kenneth, on the west side of Mull, and on the shores of the peninsula of Gribun, opposite to it. Here the unconformity between the Poikilitic strata and the older rocks, which here consist of purplish quartzite and gneiss, is quite as beautifully exhibited as at Gruinard Bay; and the following sketch taken near the little cave known as Beg's Cave will afford a good idea of the relations of the strata at this point (see fig. 8).

On the eroded edges of the old metamorphic rocks, which lie in vertical and contorted positions, lies a very coarse conglomerate, often containing angular and subangular fragments, a breccia composed of such fragments being always found at the base. Tracing the conglomerates upwards we find them alternating with and passing into irregular bands of greenish and mottled sandstone, with some beds of concretionary limestone and occasional marly beds and thin layers of gypsum.

The thickness of the Poikilitic strata at Gribun is considerable; and their summit is not seen, as they are unconformably overlapped by the beds of the Cretaceous series. Indeed, as we shall see hereafter, the beds of the Upper Greensand are so similar in character, being made up of materials derived from the Poikilitic, that it is impossible to draw any sharp line of demarcation between them, though their difference of age is so enormous, and in other localities they are separated by thousands of feet of strata. To the west the Poikilitic strata of Gribun, with the overlying Cretaceous, rise gradually in the cliff till they are overwhelmed and concealed by the vast taluses descending from the overhanging basaltic precipices of the grand peninsula of the Bourg. It is probable, too, that they are cut off to the west by a great fault, which carries them below the sea-level.

Fig. 8.—*Sketch taken near Beg's Cave, on the Southern Shore of Loch na Keal, opposite Inch Kenneth.*



a. Conglomerates and sandstones of Poikilitic age, covered by Cretaceous (Upper Greensand) strata.
b. Purple quartz, quartz-schist and gneiss.

In concluding this account of the Poikilitic strata of the Western Highlands, it is impossible to abstain from again expressing the strongest protest—a protest based on convictions that have gained strength with successive years of work in the district—against the acceptance of negative evidence in this case, and against the view that similar strata to those exposed at so many points between Gruinard Bay and the Gribun might not originally have extended far beyond those limits. When we look southward to Antrim and northward to Sutherland and Elgin, where beds of similar age and character reappear, we cannot but feel that it is impossible to limit the former extent of this formation to the particular regions wherein traces of it have been accidentally preserved, or to avoid the conclusion that wide areas now exhibiting no traces of deposits of this age were once buried under hundreds, or even thousands, of feet of the Poikilitic beds.

C. The Jurassic System.

As already pointed out in the introduction to this paper, the fact of the existence in the Western Islands of Jurassic deposits of considerable thickness and importance has long been known to geologists. The results, moreover, of the labours of Murchison, Geikie, and Bryce, as interpreted by the palæontological studies of Sowerby, Forbes, Wright, and Tate, leave us little room for doubt as to the true correlation of the various strata which are seen in the grand sections of Skye and Raasay with the equivalent deposits in England. As these results, accompanied by detailed lists of fossils, are published at various times in the Transactions and Journal of this Society, and have further been very well summarized in the 'Catalogue of the Western Scottish Fossils,' the introduction to which is from the pen of Dr. John Young, it will be quite unnecessary for me to recapitulate the conclusions which have been already arrived at.

But, inasmuch as a great number of the less accessible sections of the Jurassic rocks in the Western Islands have hitherto been very imperfectly described, while some have hitherto remained altogether unnoticed, it seems to me desirable to consider these in connexion with those concerning which we already have a considerable amount of information. By doing so I hope to be able to show what was the distribution of the several members of the Jurassic series in this district, to illustrate the remarkable changes in character which some of them are found to undergo when traced over considerable areas, and thus to pave the way for arriving at a satisfactory basis on which to found a discussion concerning the physical geography of the district and of the conditions which prevailed in it during the periods when these strata were deposited. At the same time I shall endeavour to correct and supplement the previously published account of the old and familiar sections, whenever such correction and addition may be found necessary.

a. *The Infralias.*

The strata which underlie the *Lima-* or *Bucklandi-*beds in Western Scotland acquire at some points such thickness and importance that it will be convenient to follow the example of French authors, and to separate them from the remainder of the Lower Lias under a distinctive title. The formation in question certainly in places exceeds 150 feet in thickness, and includes strata both of marine and estuarine origin. Even the marine beds, however, very commonly exhibit clear evidence of the prevalence of littoral, and sometimes of brackish-water conditions, during their accumulation; and the whole formation thus constitutes a transition series between the probably lacustrine Poikilitic below and the undoubtedly marine Lower Lias above. The dwarfed forms of the oysters and other shells of the Infralias of this district, and the absence of the Cephalopoda from it, may be cited as warrant for these observations; but it must at the same time be remembered that some purely marine beds, crowded with corals and univalves, also occur in its midst.

The most conspicuous and characteristic strata of the Infralias are certain very hard bluish-grey limestones, sometimes compact, at others subcrystalline, and occasionally oolitic in structure. These limestones are not unfrequently found to be crowded with fossils; but such is the hardness and intractability of the matrix in which they are enclosed, that it is seldom possible to disengage them in any thing like a satisfactory condition. Certain beds crowded with specimens of *Ostrea irregularis*, Münst., occur in the series, and others almost wholly made up of corals; and these latter beds abound with species of Gasteropoda, few of which, however, can be obtained in a sufficiently perfect condition for specific determination.

The limestones above described alternate with beds of sandstone and calcareous grit, which often contain numerous pebbles of quartz, and occasionally pass into conglomerates. At Applecross, where they can be very conveniently studied, these arenaceous strata intercalated in the Infralias are clearly of estuarine origin, and contain thin and imperfect seams of coal; but in Skye, Ardnamurchan, and Mull the sandy strata of the Infralias, though clearly of littoral origin, appear to contain marine fossils throughout.

There seems to be no room for doubt that the Infralias strata of the Western Isles are perfectly conformable with the subjacent Poikilitic, into which in some cases they appear to graduate downwards insensibly. The locality in which the details of the series of strata can be best studied is that of Applecross; but here the thickness of the series cannot be determined; on the shore of Raasay, opposite to Applecross, this thickness can be estimated, though the details cannot be well made out. The result of a careful examination of the question shows that the thickness of the Infralias in Raasay and Applecross cannot be less than from 150 to 200 feet; while in Strath in Skye, as seen between Lussay and Obe Breakish, the formation has at least an equal development. In the interior of the island of Skye, about Kilbride and Loch Slapin, the Infralias limestones, repeated by faults, are found to be greatly altered in consequence of the proximity of the great intrusive masses, and pass into fine saccharine marble and ophicalcite, as described by Dr. Macculloch and Prof. Geikie. The sandstones which alternate with the limestones are changed into quartzite.

The Infralias, when traced southwards from Applecross, Raasay, and Skye, is found gradually to lose its importance, and to become diminished in thickness. While in Ardnamurchan the strata in question are moderately well developed, in Morvern and Mull they are seen to be reduced to a comparatively rudimentary condition. Possibly in the extreme south of the island of Mull they regain something of their former thickness; but, unfortunately, the rocks are here so greatly altered, and their fossils so completely obliterated through their proximity to igneous intrusions, that it is impossible to arrive at any certain conclusion as to where one formation ends and another begins.

It is worthy of remark that in the Infralias of the west coast of Scotland the "Zone of *Avicula contorta*" does not appear to be distinctly developed.

The section of the Infralias strata at Applecross is probably without its equal in the British islands, whether we regard the thickness of the strata representing the period, or the variety and beauty of their fossil contents. Instead of the thin beds which occupy this horizon in England, we find thick masses of limestone alternating with estuarine strata, the former resembling the equivalent beds of Western France, the latter those of Scania. Unfortunately the complete series of the beds and their relation to the overlying deposits cannot be traced in any one continuous section, and the fossils, though numerous, are enclosed in so hard a matrix as to be very difficult of extraction. At the burn called Allt-Breugach and in a tributary stream a tolerably good succession of the strata can, however, be made out. The remarkable relations of this singular patch of Jurassic strata, and the curious combination of circumstances to which it owes its preservation, have been already commented on, and are illustrated by the plan and section (fig. 3, p. 672). Where the Cambrian sandstones are faulted against the calcareous beds of the Infralias the line of junction is very well marked, the copious streams which flow over the first-mentioned rocks being immediately lost in swallow-holes on reaching the latter.

The succession of strata of Infralias age at Applecross is as follows (in descending order):—

	ft.	in.
(1) Oolitic limestone with *Cardinia concinna* and other shells, with beds of shelly limestone below crowded with *Ostrea irregularis* .	50	0
(2) Alternations of limestones with calcareous grits and shales, and occasional beds of Oysters. (The thickness of (2) is considerable, but could not be exactly determined.)		
(3) Great series of sandstones, grits, and conglomerates with coal-seams, exhibiting clear evidence of shallow-water and estuarine conditions. This series is about 30 ft. thick, and exhibits the following members in the Allt Breugach:—		
a. Thick-bedded sandstone and grit (occasionally calcareous), forming a well-marked escarpment at the highest point at which the Jurassic beds are exposed in the Allt Breugach. The only fossils found were fragments of a gigantic *Pinna* near the base of the bed	11	0
b. Bed of conglomerate with scattered pebbles of white and pink quartz		9
c. Masses of sandstone similar to *a*, but generally more thinly bedded, passing into soft occasionally ferruginous sands on the one hand, and into fissile sandy beds on the other. These fossil beds contain spines of *Acrosalenia* and *Cidaris*, ossicles of *Pentacrinus*, and small univalves. Some others among the beds pass into a coarse calcareous grit, while in portions of the mass small quartz-pebbles are found abundantly scattered	12	0
At one point in this series of beds an inconstant seam of coal, of good quality but only an inch or two in thickness, was exposed in 1872, when I first visited this section.		
d. Thick bed of hard sandstone passing into calcareous grit, pebbly in places, and containing a few shells of *Ostrea* filled with crystallized carbonate of lime..................................	3	6
e. Laminated sandy shales of a light blue colour, with a few bands of hard grit	1	3
f. Bed of hard blue calcareous grit	2	0
g. Bed of hard blue ferruginous shale indurated in some places...	2	6

At this point an intrusive sheet of coarse dolerite, about 6 feet in thickness, destroys the continuity of the section. It alters in a very marked manner both the beds above and those below it.

	ft.	in.
(4) Alternating beds of shale and calcareous grit with few fossils, except casts of univalves	14	0
(5) Bed of grey compact limestone with partings of clay. Fossils are by no means rare in this bed, but are very imperfectly preserved. Among them occur spines of *Acrosalenia*, shells of *Ostrea irregularis*, *Lima Hermanni* (?), *Phasianella* (?) sp., *Rhynchonella* sp., and *Thecosmilia Martini*	6	0
(6) Shales and sandy beds imperfectly seen, passing downwards into hard calcareous grits with carbonaceous markings, which alternate with dark blue shales. These beds contain only few and very imperfectly preserved fossils	20	0
(7) Beds of hard argillaceous limestones, compact or occasionally oolitic, sometimes becoming sandy in character; these alternate with dark blue shales containing nodular bands of hydraulic limestone of a whitish colour. The limestones are occasionally crowded with univalves and corals, and sometimes almost made up of shells of *Ostrea irregularis*. Other fossils are common, but very difficult of extraction.		
(8) Below the last beds of limestone are found traces of another series of estuarine strata (exposed near the old mill of Applecross), which consists of soft yellow sandstones, grits, and conglomerates, in the lower part of which a coal-seam of some thickness was once exposed	?	
The base of this series is not seen.		

Unfortunately this interesting section of the Infralias strata in Applecross is very imperfect; for while, as we have seen, its base is nowhere exposed, it is equally impossible to trace the relation of the thick series of strata to the *Lima-* or *Bucklandi*-beds, which make their appearance at another point in the Applecross district.

Besides the sections in the burns at Applecross, there are some other exposures of the Infralias in the district which are of considerable interest. Thus in a stone-pit behind Applecross House a series of beds of limestone of a blue colour, but weathering white and of beautifully oolitic structure, is seen to the depth of about 15 feet. Each floor of limestone is about 1 ft. thick; and they are not separated from one another by partings of shale. The usual fossils are found here, *Ostrea* (*Terquemia*) *arietis*, Quenst. sp., being especially abundant and characteristic. The same beds are found dipping seawards at the village, at an angle of from 10° to 12°, and are here traversed by an intrusive sheet of dolerite. These limestones abound with specimens of corals, gasteropods, and oysters.

Between the village and Applecross House masses of sandstone not *in situ* are found, which contain coaly seams and many obscure plant-remains, some of the latter being in a vertical position with respect to the beds.

From the space occupied by the Infralias beds in the great Cliff-section of Raasay (see fig. 2, page 671) it is clear that the strata of this age must have a thickness of from 150 to 200 feet; but the details of their succession can nowhere be distinctly followed. It is evident, however, from an examination of the beds irregularly exposed in the midst of the masses of talus which overwhelm and obscure all this part of the great cliff-section, that, as in the opposite coast at Applecross, we have marine strata consisting of compact, shelly, and oolitic limestones of a pale blue colour, occasionally abounding with corals, which alternate with thick masses of littoral origin, consisting of shales, sandstones, and grits, with thin and inconstant seams of coal in their midst.

Very interesting for comparison with the section of Infralias strata of Applecross is that exposed along the north shore of Strath between Lussay and Obe Breakish. The beds are only seen in a series of shore-reefs; and their thickness can be estimated only roughly. No estuarine strata are found at this horizon in Skye; but the highest member of the series consists of beds of coarse white sandstone, exhibiting in its false-bedding and other characters clear evidence of having been deposited under estuarine conditions. These sandstones are quite destitute of fossils, and immediately underlie and pass up into the shales and sandstones of the *Bucklandi-* or *Lima*-series.

The Strath section is as follows:—

	feet.
(1) White sandstone, occasionally containing quartz pebbles, and passing into conglomerates. No fossils yet found	30
(2) The Obe-Breakish limestones and shales. One of the upper beds is crowded with *Thecosmilia Martini**, E. de From., and forms a veritable coral reef. *Ostrea* (*Terquemia*) *arietis*, *O. irregularis*, a gigantic *Pinna*, and many univalves also occur at the same horizon. The limestones are usually compact, but occasionally are very shelly, being almost made up of masses of *Ostrea irregularis*: they alternate with bands of dark blue shale. These beds are repeated by faults at Broadford (where they are burnt for lime), and appear at many points inland and on the south side of the district of Strath, where they are usually much altered by igneous intrusions, passing into saccharine limestone and ophicalcite. The thickness of this set of beds cannot be less than	150
(3) Calcareous sandstones, the surfaces of the beds of which are covered with casts of *Cardinia concinna*	7 to 8
(4) Another coral reef, formed of *Isastræa Murchisonæ*, underlain by a compact bed of limestone	3
(5) Greenish and chloritic sandstone, with irregular ferruginous concretions passing down into calcareous grit, and then into hard subcrystalline limestone containing only very obscure traces of shells (*Ostrea irregularis*, Münst.).	

Only about 9 feet of these beds are exposed; and they lie directly upon the thin representative of the Poikilitic strata of this place (see page 691)†.

* I am indebted to Prof. P. M. Duncan for examining the corals from the west coast of Scotland.

† As one of the most serious and apparently best-circumstantiated charges against the good faith of Dr. Macculloch has been based on a criticism of his description of the strata at this point, it may be as well to examine this charge in detail. We are told that Macculloch commences the line of junction of the Secondary beds and Torridon Sandstone "at the head of the long narrow creek of Obe Breakish, instead of at the village of Lussay, thus colouring as Red Sandstone a space two miles in length, which is actually Lias" (Quart. Journ. Geol. Soc. vol. xiv. 1858, p. 3). But an examination of Macculloch's map, which is taken from a very old and imperfect chart (the best basis he could obtain for his geological observations), will convince any unprejudiced observer that the error

In Ardnamurchan, Mull, and Morvern the Infralias is not exhibited in any good connected sections. The strata of this age appear, indeed, to be of insignificant thickness as compared with their equivalents in Skye, Raasay, and Applecross, and occasionally seem to be on the verge of total disappearance. At the outlier of Beinn-y-Hattan the Infralias appears to have thinned out altogether. There are some isolated deposits in the north of Mull (as at Ru-na-Gal, Calve Islet, and one or two other points) which, though probably of this age, are in too altered a condition for satisfactory determination. At Torosay, and again between Duart House and Duart Castle, the compact limestones and pebbly grits of the Infralias are fairly well exposed, but do not attain any great thickness. The same is the case with some larger exposures on the south side of the island of Mull.

b. *The Lower Lias.*

The strata of this age are very largely developed in the Hebrides and adjacent mainland of Scotland, and constitute a series of deposits (often richly fossiliferous) with a total thickness, in some places, of at least 400 feet. In the most southern part of the area we are describing, the Lower Lias beds most strikingly resemble, both in their mineral and palæontological characters, their equivalents in England; and the great floors of limestone and shale crowded with *Gryphæa arcuata*, Lam., and abounding in *Lima gigantea*, Sow., and Ammonites of the group of the *Arietes*, which are so well exposed at Loch Aline and some other points in the Western Highlands, cannot fail to recall to the mind of the most superficial observer the strata of the same age in this country, namely the well-known *Lima*- or *Bucklandi*-beds.

But when traced further northwards, these strata are found undergoing some remarkable changes in their characters and fossil contents—changes which tell unmistakably of the prevalence of somewhat different conditions as existing in those parts of the Liassic sea.

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lies not with Macculloch, but with the map on which he recorded his observations. It is clear that the indentation of the coast where the two formations are made to meet is intended for the harbour of Lussay, and not that of Obe Breakish, as the later writer supposes; and this is shown by the fact that the name of "Lucy" is inserted on the map and mentioned in the text of the work as occurring at the point of junction of the two formations. (Western Isles of Scotland, vol. i. p. 319.) It is greatly to be regretted that a writer in the Journal of this Society, basing his criticisms on this and equally mistaken premises, has permitted himself to make charges of actual fraud against his predecessor. Nothing is easier than this criticism of the old work of a geological pioneer by one who is furnished with accurate modern maps, and has the advantage of the discoveries of later thinkers to guide him. But surely before such a painful charge was made it would have been more fitting that the utmost care should have been taken to avoid misrepresentation, that the fullest consideration should have been given to all the facts of the case, and the amplest allowance made for the difficulties under which Macculloch laboured in the want of even approximately accurate maps, at the early date (1819) at which his researches were carried on.

Thus in Skye and the adjoining districts we find the Lower-Lias limestones and shales exhibiting a tendency to assume a more sandy character, the former passing in many cases into a calcareous grit, and the latter into an argillaceous sandstone; while in some places masses of coarse sandstone and quartzose conglomerate make their appearance in the series; and these certainly seem to indicate the proximity of an ancient shore-line. Nowhere, however, do we find proofs of the prevalence of actual estuarine conditions in the midst of the Lower Lias of the Western Highlands in the same manner in which we have shown such to occur among the equivalent deposits in Sutherland.

The sandstone, grits, and conglomerates intercalated in the Lower Lias series of the Hebrides are usually very unfossiliferous; they, however, occasionally exhibit some evidences of having been accumulated near to land, in the abundant fragments of wood which they contain. The conglomerates are usually made up of well-rounded pebbles of white quartz; and only few and often obscure casts of shells occur in them; these, however, enable us to pronounce with certainty as to the marine origin of the beds which contain them.

In the limestones and shales the fossils, of which individuals are particularly abundant in the Lower Lias of the Western Highlands, serve clearly to indicate the position of the several beds in the geological series. Although, however, individual fossils are so exceedingly abundant, the number of species which can be recorded is by no means so great as would be at first sight anticipated; they are nevertheless amply sufficient for defining the geological horizons of the beds in which they occur.

The great mass of the strata in question clearly belongs to the "*Lima*-beds or Zone of *Ammonites Bucklandi*." This is proved by the remarkable abundance of *Gryphæa arcuata* of the typical form, and by the numerous and fine examples of *Lima gigantea* which occur —and especially by the prevalence of such characteristic arietiform Ammonites as *A. Bucklandi*, Sow., *A. Conybeari*, Sow., *A. Kridion*, Hehl, and many others. Many other fossils which occur with these, such as *Nautilus striatus*, Sow., *Pinna Hartmanni*, Defr., *Lima succincta*, Schloth., and *L. pectinoides*, Sow., *Spiriferina verrucosa*, v. Buch, *S. Walcotti*, Sow., serve to confirm the correctness of the identification of these beds with the well-known deposits of England, Burgundy, and Württemberg.

I have in another work* pointed out the fact that in Lincolnshire the upper part of the *Bucklandi*-beds presents some peculiarities in its fauna which are well worthy of notice and that the deposits on this horizon in that county, which have now become so well known on account of the thick masses of valuable ironstone which they contain, clearly represent that subzone to which Dr. Oppel applied the name of zone of *Ammonites geometricus*, Phill. (an Ammonite which is now regarded as identical with *A. semicostatus*, Y. & B.).

* Memoirs of the Geological Survey of England and Wales—"The Geology of Rutland," &c. pp. 42–45.

Precisely the same observation holds good with respect to the Lower Lias strata of the Western Highlands. Here, as in Lincolnshire, we find that the upper part of the "*Lima*-beds," which exhibits some peculiarity in its mineral characters, can also be separated by the presence of certain interesting and well-marked forms of *Ammonites* and other shells from the great mass of strata below.

It seems to me that this partial change of fauna is by no means unworthy of record in the description which I propose to give of the Lower Lias of Scotland. The changes in the characters of the Ammonites which characterize this upper portion of the "*Lima*-beds" is especially remarkable and significant; and what is most important of all is, that precisely parallel changes can be traced as making their appearance at the same point in the geological series in Scotland, the North of England, and in Swabia. Thus, while the Ammonite forms (I hesitate to call them species) so abundant in the Lower Zone (Zone of *Ammonites Bucklandi*) disappear, a new group of forms, with a most unmistakable family resemblance, takes their place in the Upper Zone (Zone of *Ammonites semicostatus*). Some of these forms, which are distinguished by certain well-marked characters which they have in common, have been already figured and described by Quenstedt; and I hope that a complete series of them, selected from the rich cabinets of the Rev. J. E. Cross, of Appleby, who has done so much towards working out the fine fauna of the Scunthorpe and Froddingham ironstones, will soon be rendered familiar to geologists by the monograph of Dr. Wright now in course of preparation. In the Western Islands we find a number of other minute peculiarities in the fauna of the Upper Zone of the *Lima*-beds, such as we also found in Lincolnshire; in both localities some new forms of Mollusca occur, others disappear, while others again exhibit distinct and characteristic varietal features: thus in both localities *Lima gigantea* assumes a size which it is never known to attain in the Lower beds; and this increased size is accompanied by peculiarities of form and surface-sculpture which are by no means unworthy of notice and study.

While, however, the inferior division of the Lower Lias (that to which Quenstedt applies the term Lias α) is so admirably developed in the Western Highlands, its upper member (Lias β of Quenstedt) appears to be wholly, or almost wholly, unrepresented in the area. In Raasay the dark shales containing the fossils of the zones of *Ammonites armatus* and *A. Jamesoni*, constituting the base of the Middle Lias (Lias γ of Quenstedt), are seen resting directly upon the *semicostatus*-beds. Only in the northern part of the Mull have I succeeded in detecting any trace of the fauna of the Lias β in the Western Highlands. At Tobermory a very fossiliferous stratum occurs (as noticed by Hugh Miller), the palæontological characters of which seem to be of considerable interest, from the fact that in it forms seem to be mingled together which elsewhere characterize the distinct zones of *Ammonites ibex*, *A. Jamesoni*, *A. armatus*, and *A. oxynotus*. The species, however, are for the most part more or less dwarfed in size in this stratum; and as there is no clear section exposed, specimens from more than a single band may easily be inadvertently mingled together by the collector. It is worthy of note, as I have pointed out in the first paper of this series, that in the Eastern Highlands the Lias β, and especially the zone of *Ammonites oxynotus*, is remarkably well represented.

I may here perhaps remark, while speaking of the identification of the successive zones of life in the Lias, that we have in Scotland some very striking examples of the manner in which a geological horizon, very feebly or not at all represented in one locality, may in another acquire distinctive features, important development, and great thickness; while, on the other hand, a zone, which in one area may consist of thick deposits that appear to be so clearly characterized as to be incapable of ever being by any possibility overlooked or confounded with another, may in a different region be represented by only a thin and inconstant stratum, and, more than this, may lose many of its most distinctive palæontological features, the fossils which elsewhere characterized it being found mingled with those of the beds above and below it.

Thus, though I perfectly agree with Mr. Blake that in Gloucestershire and Yorkshire the Subzone of *Ammonites semicostatus* can scarcely be separated from the Zone of *A. Bucklandi*, yet in Lincolnshire and the Western Highlands such a division is natural, useful, and, I think I may add, indispensable. In the same way the established division of the Lias γ, which is so well developed in Swabia and Yorkshire, might be thought in the Western Highlands to be wholly unnecessary; for scarcely any trace of it is there found.

Nor do these remarks tend to throw the smallest discredit upon the system of classifying strata into palæontological zones, when that system is rightly understood and properly applied. The different quantities of sediment deposited in various portions of the same sea, dependent as that is primarily on the amount of subsidence taking place at a particular time in certain portions of the ocean-bed, will cause the same period of geological time, and the same stage in the history of a fauna, to be very unequally represented by thickness of deposits. The advance of our knowledge may be expected to result in the constant intercalation of new zones of life between the old ones which had before seemed separated by distinct breaks; and by this means some of the imperfections and consequent anomalies of the palæontological record will be removed. In this way we shall be led to entertain more just and correct ideas as to the true succession of life-forms, and have afforded to us fuller materials for investigating the means by which that succession of forms has been brought about.

The most northerly point on the west coast of Scotland at which traces of the Lower-Lias strata have been found is at Tinivulin (Tigh-na-Fiolan), on the north side of Loch Ewe. At this place, however, no Lias strata are exposed *in situ*; but numerous blocks of Lias limestone are found scattered upon the shore, and from these I collected the following fossils:—*Ostrea irregularis*, Münst.; *Gryphæa arcuata*, Lam.; *Pinna Hartmanni*, Ziet. sp.; *Lima succincta*, Schloth. sp.; *Lima gigantea*, Sow.; and fragments of Echinodermata. It is evident that these have been derived from the Boulder-clay, which is so extensively developed in the peninsula which separates Loch Ewe from Gruinard Bay; and, as pointed out by Professor Nicol, their abundance lends support to the conclusion that beds of this age are now concealed by Glacial drift, or at all events that they were in existence in the immediate neighbourhood at the very recent geological period when those deposits were accumulated. It is scarcely necessary for me to recall attention to the fact of the frequency with which we have to appeal to evidence of the same kind on the east coast of Scotland, where abundant traces of the different members of the Cretaceous and Jurassic systems are found in the Boulder-clay and gravels of the area; though as regards some at least of them it is certain that no trace of the existence of beds *in situ*, which contain the same characteristic fossils, can anywhere be detected.

Among the fragments of limestone derived from the Boulder-clay at Loch Ewe, and which were once collected in sufficient abundance to supply a lime-kiln, there are found representatives of both the Infralias and the Lower Lias. It is probable that the patch of Poikilitic strata let down by faults at Gruinard Bay, and now so greatly obscured by drift-deposits, is, or at all events was at the time of the Glacial period, capped by Rhætic and Liassic strata.

At Applecross, however, there can be no doubt that the *Lima*- or *Bucklandi*-beds of the Lower Lias occur *in situ*. In the year 1872 I was so fortunate as to see some excavations made in the district between the two burns in which the sections of the Infralias beds, already described, were found. These excavations were made in deepening a watercourse, and exposed beds of limestone-rock crowded with *Gryphæa arcuata*, Lam., of the typical form, and containing also many other shells characteristic of the Lias α. The great floors of rock crowded with *Gryphææ* were especially striking here.

Among the fossils that I collected at this locality were *Ammonites kridion*, Hehl, *Gryphæa arcuata*, Lam., *Lima gigantea*, Sow., *L. succincta*, Schloth. sp., *L. punctata*, Sow. sp., *Modiola psilonoti*, Quenst., *Avicula sinemuriensis*, D'Orb., *Pecten textorius*, Schloth., *Pecten*, sp., *Unicardium cardioides*, Phill., *Cardinia Listeri*, Sow. sp., *C. crassiuscula*, Sow. sp., *Cardinia*, sp., *Astarte dentilabrum*, Eth. Many of the beds of rock were seen to be completely made up of these and other shells.

Fragments of the same strata are found along the shores of Applecross Bay to the north of the Old-Mill burn. Some of these fragments are crowded with the ossicles of *Pentacrinus*; and in one of them I found a gigantic specimen of *Ammonites Bucklandi*, Sow., with *Ostrea* (*Terquemia*) *arietis*, Quenst. sp., attached to it.

So far as the limestones of Applecross Bay are concerned, they are identical in their characters and fossils with the Lower-Lias limestone floors of England. They appear here to alternate with thick beds of shale, which are, however, nowhere well exposed in section.

In the great cliff-section of Raasay lying opposite to Applecross Bay the *Lima*-beds are fairly well exposed, the floors of limestone standing out from among the intervening crumbling shales in a very striking manner. It is over one of the higher of these floors of limestone that the burn of Hallaig tumbles into the sea, giving rise to a very picturesque waterfall. The thickness of the Lower Lias here cannot be less than 200 feet. At its upper part the sandy argillaceous beds, containing peculiar forms of *Gryphæa arcuata* and the Ammonites which characterize the Zone of *Ammonites semicostatus*, are found; and these are seen to be directly overlain by the shales containing the fossils of the Zone of *Ammonites armatus*.

On the northern slope of Beinn Glamaig in Skye and along the shores of Loch Sligachan the Lower-Lias and Infralias strata are found thrown up at very high angles (from 32° to nearly vertical); they are, however, frequently greatly altered by their contact with the syenite, and their fossils are scarcely recognizable.

The best sections of the Lower Lias in Skye are those exposed along the shore of Broadford Bay, between Obe Breakish to near the village of Broadford, at which latter place the Infralias strata are brought up again by a fault. Here the succession of beds is as follows:—

Above the white sandstone and grit, passing into conglomerate, which we regard as constituting the highest member of the Infralias (though, as they contain no fossils, it may be equally allowable to include them in the Lower Lias), we find a series of dark-coloured, almost black micaceous shales, with only occasional limestone floors, crowded with fossils, which occur both in the shales and limestones, but most abundantly in the latter. The following species were observed:—*Ammonites Bucklandi*, Sow.; *A. Conybeari*, Sow.; *Pleurotomaria similis*, Sow. sp.; *Gryphæa arcuata*, Lam.; *Lima gigantea*, Sow. (normal form); *Cardinia Listeri*, Sow.; *Pecten textorius*, Schloth.; *Pecten*, sp.; *Pinna Hartmanni*, Goldf.; *Unicardium cardioides*, Phil. sp.; *Avicula sinemuriensis*, D'Orb.; and *Spiriferina Walcotti*, Sow. sp. These beds are probably at least 150 feet in thickness.

This series of black, highly micaceous shales is continued upwards by beds of precisely similar mineral character, which, however, contain a slightly different fauna. The typical form of *Gryphæa arcuata*, Lam., with a deep sulcus, is replaced by a variety of the same shell far less conspicuously sulcated. The Ammonites allied to *A. Bucklandi*, Sow., disappear; and in their place we find very abundantly *Ammonites semicostatus*, Y. & B., *A. Sauzeanus*, D'Orb., and several other peculiar forms. The typical form of *Lima gigantea*, Sow., is no longer found; but in its place occurs a variety of greater flatness than the type and of peculiar form. These beds evidently represent the zone of *Ammonites semicostatus*. Their full thickness, however, is not seen at Broadford Bay, as they are faulted against the Infralias strata, which a little to the westward are quarried for lime-burning.

Although the Lower-Lias strata are exposed at many other points both in the interior and along the southern shore of the district of Strath in Skye, yet they nowhere afford good sections. In many places the strata are so altered, as in Strathaird and along the shores of Lochs Eishart and Slapin, that scarcely a fossil can be recognized.

in the beds of indurated black rock (resembling Lydian stone) and the crystalline limestone with ophicalcite, into which the shales and limestone are respectively altered. Even here, however, their relation to other rock-masses of known age, and the occurrence of an occasional fossil, enable us to assign the beds in question to their true position in the geological series.

From the above description it will be seen that the Lower Lias of Skye, Raasay, and Applecross appears to differ from the normal type by the smaller development of the limestone-floors and the prominence of the intervening masses of black micaceous shale. The more northern area of the Lower Lias is cut off by a considerable interval, in which no traces of the formation are found, from the districts of Ardnamurchan, Morvern, and Mull, in which we find exposures of the Lower Lias assuming characters much more nearly in conformity with those of the typical beds in England. In the southern district of the Western Islands the beds of limestone are much more fully developed than in the northern area; and the English geologist is everywhere struck by the very close resemblance of the oft-repeated limestone-floors, with only thin shaly partings between them, to the strata of equivalent age in the southern part of this island.

In the peninsula of Ardnamurchan the Lower-Lias strata are met with at various points, but good exposures of them occur only in the sea-cliffs. On the north side of the peninsula the cliffs at Surdil exhibit great masses of limestone alternating with shale, and crowded with *Gryphæa arcuata*, Lam., and other fossils. These beds rest on the compact limestones and calcareous grit of the Infralias, which in turn repose on the representative of the Poikilitic. The upper portions of the Lower-Lias strata at Surdil have undergone great metamorphism, being traversed in all directions by innumerable dykes; in this part of the series the limestones become highly crystalline, and every trace of fossils is obliterated.

On the south side of the peninsula of Ardnamurchan the Lower-Lias limestones are well exposed in the reefs below the picturesque ruins of Mingary Castle, and for a considerable distance along the shore between Kilhoan and Sron More. The beds are in places considerably interfered with by masses of basalt, forming both intrusive sheets and dykes. The lowest beds of the Lower Lias here, which are seen directly reposing on the compact limestones of the Infralias, consist of limestones of somewhat sandy character containing numerous specimens of *Gryphæa arcuata*, Lam., of the typical form. Beds almost made up of the ossicles of *Pentacrinus* occur here.

The highest beds of the Lower Lias, which are greatly altered on the north side of the Ardnamurchan peninsula, are, on the south side, admirably exposed; and the alteration which they have undergone is small in extent and of merely local character, being confined to the immediate proximity of the masses of intrusive rock. We here find, too, clear proofs of the presence of the Subzone of *Ammonites semicostatus*. It is represented by a thick mass of dark micaceous shale, with only occasional limestone bands, very similar in character to the equivalent strata in Broadford Bay, Skye. In these beds I found the following fossils, which are tolerably abundant:—*Ammonites Brookii*, Quenst. (non Sow.); *A. semicostatus*, Y. & B.; *A. falcaries*, Quenst.; *A. Sauzeanus*, d'Orb.; *Belemnites acutus*, Mill.; and the abnormal form of *Gryphœa arcuata*, Lam., which is characteristic of this horizon in the Lower-Lias series.

In the district of Morvern the Lower-Lias strata are especially well developed, and are remarkable alike for the abundance of their fossils and the striking agreement in character with the equivalent beds in England.

Nowhere, indeed, can the Lower Lias of the Western Highlands be studied to greater advantage than on the shores of "green Loch Aline," which opens on the eastern side of the Sound of Mull. On the western side of the Loch, a few hundred yards above the village, the floors of Lower-Lias limestone form reefs on the shore which are uncovered at low water; and from these the fossils, beautifully weathered out, can be collected in the greatest abundance and perfection. The beds have a gentle dip to the south, and are seen to be covered unconformably by the strata of Upper-Greensand age, which are so well exhibited here. Further up the Loch, and on the same side of it, there are two old quarries where the stone has been worked for lime-burning; and at various points in the wooded cliff and along the shelving shore exposed at low-water the same beds can be traced.

Crossing to the opposite or eastern side of the Loch we find, besides numerous small exposures, a magnificent section, probably not less than 70 or 80 feet in depth, showing admirably the alternating floors of Lower-Lias limestone and shale crowded with fossils. This is certainly one of the finest and most interesting sections of the Lias in the Western Highlands; the number and beauty of preservation of the organic remains are surprising, and are sufficiently remarkable, indeed, to arrest the attention even of an observer accustomed to the most admirable and fossiliferous exposures of the English Lias.

Near Ardtornish Point, outside Loch Aline, at the part of the shore below the famous Castle which stretches furthest to the southwards, beds of limestone, crowded with the typical forms of *Gryphœa arcuata*, Lam., and *Lima gigantea*, Sow., are seen in the reefs exposed at low water. Here I collected several very large specimens of *Ammonites Bucklandi*, Sow. Still further to the east, where the grand basaltic cliffs of Ardtornish commence, the *Bucklandi*-beds, crowded with the same characteristic fossils, are again exposed on the shore near the keeper's lodge; and a ruined lime-kiln close by indicates that the beds were once burnt for lime at this point.

Inland, around the shores of Loch Arienas (L. Conich), the Lias strata are nowhere exposed except in the remarkable outlier of Beinn-y-Hattan. Over a great part of this area there is an unconformable overlap of the Upper-Greensand and overlying Cretaceous strata, the Lias strata having been removed by denudation before the deposition of the Cretaceous rocks. The section at Beinn-y-

Hattan is especially interesting, as exhibiting a last vestige of the usually grandly developed Lower Lias of this area. Only a few feet of Lias strata are here found cropping out from beneath the unconformably superposed Cretaceous; but the age of the beds is, fortunately, placed beyond question by the discovery of the following fossils—*Gryphæa arcuata*, Lam., *Unicardium cardioides*, Phill. sp., *Cardinia Listeri*, Sow. sp., *Lima pectinoides*, Sow. sp., *Pecten*, sp., and *Pentacrinus*, sp. The strata containing these fossils exhibit all the usual characters of the Lower Lias, consisting of alternating limestones and shales; they appear to rest directly upon the Poikilitic; and certainly the Infralias, if present at all, must be reduced to insignificant proportions.

As indicating the richness of the fauna of the Lower-Lias strata around the shores of Loch Aline, we may cite the following list of fossils found there:—

Vertebræ of *Ichthyosaurus*.
Ammonites Bucklandi, *Sow.*, very large.
—— multicostatus, *Sow.*
—— Conybeari, *Sow.*
—— kridion, *Hehl.*
—— spinaries, *Quenst.*
—— spiratissimus, *Quenst.*
——, sp.
Nautilus striatus, *Sow.*
Phasianella (?), sp.
Cardinia Listeri, *Sow.* sp.
Myacites liasinus, *Röm.*
—— alduinensis ?
Pholadomya glabra, *Ag.*
Astarte dentilabrum, *Eth.*
Pinna Hartmanni, *Goldf.*
Lima gigantea, *Sow.* sp. } both very large
—— succinata, *Schl.* sp. } and abundant.
—— pectinoides, *Sow.* sp.
Avicula sinemuriensis, *D'Orb.*
Pecten textorius, *Schloth.*
—— Hehlii, *D'Orb.*
——, sp. [(rare).
Ostrea (Terquemia) arietis, *Quenst.* sp.
Ostrea, sp.
Gryphæa arcuata, *Lam.*, typical form in enormous abundance.
Serpula, sp.
Spines of *Acrosalenia*.
Pentacrinus tuberculatus, *Mill.*
—— briareus, *Mil.*
Large Fucoid (?) markings.

At one or two points in the vicinity of Loch Aline the ordinary *Bucklandi*-beds, which, as we have seen, are so well developed, are seen to be covered by thick masses of dark micaceous shale; and in these I have detected, at more than one locality in the district, the fossils which characterize the Subzone of *Ammonites semicostatus*. The beds on this horizon, however, are nowhere well exposed in good sections in the district in question; but, taken altogether, the exposures of the Lower Lias in the district of Morvern are without a parallel, whether we regard the clearness of the sections of the strata or the variety and admirable preservation of the fossils which they yield, in the whole of the Western Highlands.

In the island of Mull, on the other hand, the sections of the Lower Lias do not present much that is worthy of note. On the shores of the Sound of Mull at Craignure (Auchenacroish), opposite to Ardtornish, the Lower-Lias limestones are seen on the shore, but are often converted (in consequence of their proximity to igneous masses) into saccharoid limestone, in which, however, the forms of *Gryphæa arcuata*, Lam., and *Lima gigantea*, Sow., can sometimes be distinguished. The metamorphism of the beds is found to diminish as we follow the series upwards; and the higher parts of the *Buck-*

landi-beds here are seen resuming their normal characters. Further east, towards Duart House, they are found to be covered by thick masses of indurated micaceous shales in which fossils are rare. I, however, succeeded in detecting in them several of the forms of Ammonite so characteristic of the Subzone of *Ammonites semicostatus*.

The Lower Lias reappears on the south side of the Island of Mull. At Carsaig the well-marked strata of the Zones of *Ammonites semicostatus* and *A. Bucklandi* are seen cropping out from beneath the Pabba Shales, which are so finely developed at this point. The older set of beds, however, is much disturbed and altered by igneous intrusions; and as we trace down the series in the direction of Loch Buy, we find the strata completely and somewhat abruptly cut off by the intrusion of volcanic masses of Miocene age. I succeeded in detecting here some of the characteristic Ammonites of both the divisions of the Lower Lias; and specimens of *Ammonites Bucklandi*, Sow., have been found which attained to a very great size. I received very great assistance during my studies of this part of the Isle of Mull from Mr. A. Maclean, of Carsaig.

In the precipitous cliffs stretching to the eastward of Loch Buy the Lower-Lias strata are probably represented. But here all the stratified masses are in such close proximity to the great igneous centre of the Mull volcano, and have in consequence undergone such intense metamorphism, that it is almost hopeless to seek to identify the several formations, their fossils having been in almost every instance completely obliterated.

c. *The Middle Lias.*

This division of the geological series is most admirably developed in the Western Highlands. It consists of two well-marked members, which can everywhere throughout the district be fairly well distinguished, though they are not separated by any sharp line of division, either physical or palæontological. The lower of these members of the Middle Lias consists of sandy shales, and it may be conveniently denominated (after the name of the island in which it is very beautifully exposed) "the Pabba Series." The upper member of the Middle Lias, in the Western Highlands, consists of a great thickness of calcareous sandstones, which, from the island in which they are equally well developed, we may call "the Scalpa Series." The palæontological evidence happily leaves us in no doubt as to the geological horizons to which these two series ought severally to be referred; for each of them contains an abundant and very distinctive fauna. By the study of these faunas it becomes clear that the Pabba Series represents Quenstedt's Lias γ, the Zones of *Ammonites Jamesoni*, *A. ibex*, and *A. Davöi* of Dr. Oppel; while the Scalpa Series is the equivalent of the Lias δ, the Zones of *Ammonites margaritatus* and *A. spinatus* of the former author.

The Pabba Shales retain remarkably uniform characters over a wide area, and consist of more or less sandy and very micaceous shales, with many limestone nodules. At many points, where exposed in the cliffs, the beds of this series are apt to be concealed by a talus of fallen blocks, which have descended from the overlying harder beds of the Scalpa Series. But at Hallaig in Raasay in the island of Pabba, and at Tobermory and Carsaig in Mull, there is no difficulty in studying the beds of the Pabba Series and of collecting their fossils, which, at all these localities, are singularly abundant, and sometimes in a fine state of preservation. The greater portion of the strata of the Pabba Series must clearly be referred to the Zone of *Ammonites Jamesoni*, which is perhaps nowhere represented by beds of such great thickness and highly fossiliferous character. At the base are some strata in which Ammonites of the group of the *Armati* abound; and these may be regarded as representing the Subzone of *Ammonites armatus* of Dr. Oppel. In their upper part, and where the sandy shales of the Pabba Series graduate into the calcareous beds of the Scalpa Series, bands of limestone nodules appear in the midst of the shales; and it is by the gradual increase in frequency of these nodular calcareous bands that the Middle-Lias beds gradually lose their argillaceous character, and pass into calcareo-siliceous rocks. Now a study of the fossils of this intermediate series of beds, which is well seen both in Raasay and Skye, shows that they represent the Zone of *Ammonites capricornis* of English geologists, and probably the Zones of *Ammonites Davöi* and *Am. ibex* of Continental authors.

The masses of calcareous sandstones constituting "the Scalpa Series" are usually highly micaceous, like the Pabba beds below; in some places they assume ferruginous, and in others argillaceous characters, but generally appear in the form of sandy limestones and calcareous grits of a grey or yellow tint. Their fossils are unmistakably those of the Zones of *Am. margaritatus* and *Am. spinatus*, the two zones being perhaps not very distinctly separated in this district. There is certainly, however, no part of the British Islands where this portion of the Middle-Lias formation is found to be represented by so vast a thickness of strata. Although the mineral characters are tolerably uniform throughout the whole of the Scalpa Series, while many of the species of fossils range from the top to the bottom of it, yet a distinction of the two zones to which its beds belong, can be made out by the prevalence of *Ammonites spinatus*, Brug., and *Gryphæa gigantea*, Sow., in its upper beds, and of the varieties of *Ammonites margaritatus*, de Montf., with *Gryphæa cymbium*, Lam., in the lower beds. Near the Sound of Scalpa, and in Strathaird, the Middle-Lias strata, though clearly recognizable by their position, have, in consequence of their proximity to the great volcanic centre of Skye, undergone such changes that many of their mineral characters have disappeared, and almost all traces of their fossils have been obliterated. Intersected as they are by multitudinous dykes, and changed for the most part into brittle quartzites and burnt shales resembling Lydian stone, it is only here and there that one is fortunate enough to detect the cast or impression of a fossil upon which to base an opinion concerning the age of the strata which contain them. Precisely the same is true of the Middle-Lias strata of Ardnamurchan, which have suffered in an equal degree with those of the southern part of Skye from their proximity to the central axis of a great volcano.

In Mull, however, the Middle-Lias beds are exposed in an unaltered condition both at Tobermory, on the north side of the island, and at Carsaig, on its south side. At both localities the beds of the Pabba Series exhibit their usual characters, while the overlying Scalpa strata appear in a somewhat different condition from that which they assume in the more northern area. In Mull the Scalpa beds are less calcareous, and consist of greenish and yellow sandstones containing far fewer fossils than their equivalent beds to the northward. In their upper part they graduate upwards into white sandstones and grits, often containing much carbonaceous matter. These changes are suggestive of the prevalence of more littoral, sometimes perhaps even passing into estuarine, conditions in the southern part of the area in question.

The most northern localities at which the strata of Middle-Lias age have been detected are on the eastern shores of Trotternish, in Skye, and the great cliff-sections of Raasay. At both these localities their presence was pointed out by Sir Roderick Murchison, who, in drawing his sections, has fallen into some confusion through mistaking parts of the Middle Lias for Inferior Oolite, the two formations being represented in this area by beds of remarkably similar mineral character. But along the shores at Prince Charles's Cave, and again on the south side of Portree Harbour, as well as in the great mural precipices of Tor Inivaig, we find numerous exposures of both the members of the Middle-Lias series. Owing to the numerous slipped masses and the inaccessibility of these precipitous cliffs, however, it is very difficult to obtain satisfactory continuous sections; and the difficulty is increased by the fact that the stratified rocks are often broken up and interrupted by intrusive sheets of basalt, and by the circumstance that their strata are subject to rapid and frequent variations in mineral characters within very short horizontal distances. This will be well seen by comparing the several fragmentary sections adduced by the late Dr. Bryce and Professor Tate (see Quart. Journ. Geol. Soc. vol. xxix. p. 317), which nevertheless serve to give a good general idea of the nature and mode of succession of the beds of this part of the Hebridean Lias. Prof. Tate has done good service to Scottish geology by recording the numerous species of fossils occurring in these strata on the east coast of Skye.

On the east side of the island of Raasay the Middle-Lias strata are magnificently developed, the total thickness of the deposits of this age being there probably not less than 500 feet. By the action of the great fault the beds are repeated so that the higher strata (the Scalpa Series) are found extending along the shore for a considerable distance on its south or downthrow side. The fossils are here very numerous alike in the sandy limestones, the calcareous shales (which often contain great concretionary nodules of limestone), and the ferruginous rock: in the latter they are in the condition of hollow casts. Among the most common fossils here are *Belemnites breviformis*, Ziet., *Ammonites margaritatus*, de Montf., *A. Engleharditi*, D'Orb., *Pecten æquivalvis*, Sow., *P. sublævis*, Phil., and *P. liasinus*, Nyst, *Gryphæa cymbium*, Lam., and *G. gigantea*, Lam., *Rhynchonella tetrahedra*, Sow., and *R. acuta*, Sow., *Spiriferina Walcotti*, Sow. sp., and *S. rostrata*, Schloth. sp.; but nearly all the well-known forms of the English Middle Lias may be found by a diligent collector of the fossils, together with a few species which appear to be peculiar to this area. Some of the beds appear to be almost made up of the shells of *Gryphæa* and *Pecten*, while calcareous concretions, crowded with *Rhynchonellæ*, are very common.

The underlying argillaceous beds (the Pabba Shales) are not so well exposed in the cliff-section, owing to the foundering of masses of the superincumbent harder beds. At the Moor of Hallaig, however, these micaceous clays cover a considerable area, and are traversed by innumerable dykes of basalt. These having been in many cases removed by atmospheric disintegration, have caused the moor to be furrowed in all directions by a series of deep trenches, which prove very dangerous to the unwary traveller. In the sides of these trenches, and in the watercourses, numerous fossils of the Pabba Shales can be found; and a list of the species from this district has been given by Professor Tate (see Quart. Journ. Geol. Soc. vol. xxix. p. 342). Both *Ammonites Jamesoni*, Sow., and its accompanying species, and *A. armatus*, Sow., with the forms usually associated with it, occur at Hallaig. The species of fossils and characters of the beds are identical with those seen at the island of Pabba.

At several other points in Raasay strata of Middle-Lias age may be detected. Thus, near Suishnish Point the Pabba Shales are seen traversed by numerous trap-dykes. Here fossils are numerous, and of the same species as at Hallaig and Pabba. Among the most numerous forms were *Belemnites paxillosus*, Schloth., *Ammonites brevispina*, Sow. (sometimes of large size), *Gryphæa obliqua*, Sow., *Pecten æquivalvis*, Sow., *P. sublævis*, Phil., and *P. liasinus*, Nyst, *Pinna folium*, Y. & B., *Hippopodium ponderosum*, Sow., and *Avicula inæquivalvis*, Sow.

The existence of inland developments of the Pabba strata is indicated by the characteristic fossils which are sometimes found; but no useful sections occur at points other than those already referred to in the island of Raasay. The exposure of the Scalpa beds in the great cliffs between Fearns and Leac is particularly fine; but, on account of the inaccessibility of the cliffs, a good continuous section cannot be obtained.

The manner in which, owing to the action of a great fault, the Scalpa beds are found lying against the Torridon Sandstones in the island of Scalpa, has been already illustrated (see page 673, fig. 4). The upper part of the Lias series here abounds with fossils, which, however, are not very well preserved. Owing to the residence for some time in this island of a former student of the Royal School of Mines (Mr. A. Grant), I was enabled to obtain a considerable number of fossils from this locality. As they serve very well to illustrate the general fauna of the Scalpa beds, which here display their typical mineral characters, consisting of more or less calcareous sandstones and sandy shales, I have appended a list of the most abundant species; hitherto only some two or three species had been recorded from the island in question:—

Belemnites elongatus, *Mill.*
Ammonites spinatus, *Brug.*
—— margaritatus., *De Montf.*
—— ——, varieties.
Cryptænia expansa, *Sow.* sp.
Pholadomya ambigua, *Sow.*
Avicula inæquivalvis, *Sow.*
Lima Hermanni, *Ziet.*
—— acuticosta, *Sow.* sp.
Pecten æquivalvis, *Sow.*
—— sublævis, *Phil.*
—— liasinus, *Nyst.*
——, sp.
Plicatula spinosa, *Sow.*
—— læviuscula, *D'Orb.*
Gryphæa cymbium, *Lam.*
—— gigantea, *Sow.*
Rhynchonella tetrahedra, *Sow.* sp.
—— bidens, *Phil.* sp.
—— acuta, *Sow.*
——, sp.
Terebratula resupinata, *Sow.*
—— punctata, *Sow.*
Pentacrinus robustus, *Wr.*
——, sp.

The exposure of the Middle-Lias strata in the little island of Pabba has often been described, and is justly celebrated on account of the abundance of its fossils and the perfect condition in which they are sometimes obtained. The dark brown micaceous shales which compose the whole of this flat grass-covered island are well exposed in the long shore-reefs, which are traversed by numerous basaltic dykes that sometimes rise like great walls above the mouldered masses of clay. Hugh Miller, in his graphic sketches of the geological features of this district, was the first, after Macculloch, to direct general attention to this rich storehouse of fossil remains; and, acting upon his suggestion, Professor A. Geikie made a considerable collection of the fossil forms occurring there, which were carefully catalogued (the new species being described, but not figured) by Dr. T. Wright*.

Although the Middle-Lias strata certainly occur at a number of points in the district of Strath, in Skye, as under Beinn-na-Cailleach in the north, and at Strathaird in the south, yet the proximity of great igneous masses has resulted in such a vast amount of local metamorphism that the fossils are almost everywhere obliterated, and the characters and succession of the beds rendered exceedingly obscure.

Precisely the same remark applies to the exposures of Middle-Lias strata in the district of Ardnamurchan, the next point southward from Skye at which they appear. Here the rocks of this age are usually metamorphosed so that no fossils are recognizable; but the order of succession of the strata, and an occasional fossil, enable us to establish the fact that certain highly indurated shales and impure limestones (the latter reduced to a highly crystalline condition through the plexus of dykes by which they are intersected) really belong to this part of the geological series.

Thus, on the east of Kilhoan Bay we find sandy micaceous blue

* Quart. Journ. Geol. Soc. vol. xiv. (1858), p. 24.

shales passing into hard sandstones and occasionally into impure subcrystalline limestones. In these beds there can be made out in places traces of Belemnites with Ammonites (too imperfect for specific identifiation), numerous Pectens of large size, and *Gryphæa obliqua*, Goldf. These certainly represent some part of the Middle-Lias series. Traced a little further to the west, the fossils altogether disappear, and the rocks pass into the so-called Lydian stone of Macculloch (burnt shale), quartzite, and crystalline limestone. There are few localities better adapted than the one in question for the study of the series of changes, and especially of the gradual obliteration of all traces of fossils in rocks, through contact metamorphism. There can be little doubt that the Middle-Lias beds are of considerable thickness in Ardnamurchan.

At Bloody Bay, on the north side of the Island of Mull, beds of sandstone of a bright red colour are found, which have been quarried for building the lighthouse of Ru-na-Gal near at hand. The eroded surface of these beds is seen to be directly covered by the Miocene basaltic lavas. The most probable horizon to which to refer the beds in question, which have not yielded a trace of fossil remains, would appear to be that of the Torridon Sandstone, in which case the locality is interesting as exhibiting the most southern exposure of strata of that series. The peculiar sections at Tobermory, now about to be mentioned, however, cause me to entertain some doubt as to whether these red sandstones may not really be an altered condition of the Scalpa Series. At present the question of the age of these beds (as is not unfrequently the case with isolated patches of unfossiliferous strata in the Hebrides) must be regarded as still an open one.

At Tobermory there appear, from underneath the basalts, beds of sandstone of a deep red colour, and dark-coloured micaceous shales. The former beds have been quarried on a small scale for building-purposes; the latter extend over the tide-way and are seen at low water; they have also been found in digging wells. These beds, like those of Pabba, seem to have been first pointed out to geologists by Hugh Miller, who, judging from mineral characters alone, regarded the red sandstones as the "Old Red." I have found in these red sandstones, however, specimens of *Gryphæa obliqua*, Goldf., though fossils are certainly very rare in them; and thus it is rendered manifest that we have here some arenaceous beds in an altered condition intercalated in the Middle Lias series. It is possible that the strata already mentioned as occurring at Bloody Bay, with others at Calve Islet and on the shores of Mull, two or three miles to the southward, none of which have yielded fossils, may all be of the same age.

The dark micaceous shales of Tobermory, which are exposed only in a small opening at the mill, as described by Hugh Miller, yielded very numerous fossils, though not in a very good state of preservation. Mr. Hugh Miller, F.G.S., who has perseveringly explored the rocks and studied the localities which his father's graphic pen has rendered famous, has made a very considerable collection of fossils from this locality; and these he has most obligingly placed at my disposal. From Mr. Miller's and my own collections I am able to give the accompanying list, which, although by no means exhaustive, will suffice to prove the beds in question to be without doubt the Pabba Shales. The fossils here are very numerous, but in a very bad state of preservation, and often very difficult of determination.

List of Fossils from the Pabba Shales at Tobermory.

Belemnites elongatus, *Mill.*
—— acutus, *Mill.*
Ammonites oxynotus, *Quenst.*
—— raricostatus, *Ziet.*
—— densinodus, *Quenst.*
—— Buvignieri, *D'Orb.*
—— ibex, *Quenst.*
—— Valdani, *D'Orb.*
Scalaria liassica, *Quenst.*
Turbo foveolatus, *Ziet.*
Pholadomya ambigua, *Sow.*
Unicardium cardioides, *Phill.* sp.
Lyonsia unioides, *Röm.*
—— scottica, *Wr.* sp.
Leda complanata, *Phil.* sp.
—— subovalis, *Goldf.*
Cucullæa Münsteri, *Goldf.*
Myoconcha oxynota, *Quenst.*
—— scabra, *Terq. et Piette.*
Arca elongata.
Mytilus hippocampus, *Y. & B.*
Limea acuticosta, *Goldf.*
Lima punctata, *Sow.*
—— succincta, *Schloth.*
Pinna folium, *Y. & B.*
Plicatula spinosa, *Sow.*
—— lævigata, *D'Orb.*
Pecten sublævis, *Phill.*
—— priscus, *Schloth.*
—— tumidus, *Ziet.*
Gryphæa obliqua, *Goldf.*

The general association of fossils at Tobermory appears to prove that the horizon represented there is the base of the Pabba shales; and we have apparently an admixture of Lower- and Middle-Lias species. This is the only locality on the west coast of Scotland at which the peculiar fossils of the Zone of *Ammonites oxynotus* have been found; and here they occur mingled with others that belong to higher horizons. On the east coast of Scotland, as we have already shown, the Zone of *Am. oxynotus* is very distinct and well developed.

At several points about Loch Aline and Ardtornish the Middle Lias beds are certainly present, but, being covered with vegetation, exhibit no section.

On the opposite shores of the Sound of Mull the dark black shales of the Pabba Series make their appearance below Duart House, but are here, as a rule, remarkably unfossiliferous, though of considerable thickness. The overlying Scalpa beds are also present, but exhibit very different mineral characters from those by which they are distinguished in their northern exposures. In Mull the Scalpa beds are represented by greenish sandstones, with but little calcareous matter, and very poor in fossils. The abundance of carbonaceous matter in some of these beds, coupled with the presence of false-bedding, ripple-markings, worm-tracts, and fucoid impressions, points to the conclusion that they originated in water of considerably less depth than their northern equivalents.

Some greatly altered rocks at Loch Spelve, on the south-east of Mull, have yielded me *Pecten sublævis*, Phill., and one or two other Middle-Lias fossils; and it is probable that the same formation is represented among the intensely altered strata of the south coast of this island.

At Carsaig strata in a less altered condition, fortunately, make their appearance. Above the Lower-Lias strata of this locality, we find the Pabba Shales well-exposed in the flats uncovered at low water; and the sandy and littoral faciės of the Scalpa Series is exhibited in the cliffs, especially at the fine waterfall behind Carsaig House and in the quarries which have recently been opened for the new buildings. The latter beds have also been quarried at some places to the westward, and make their appearance at many points in the cliffs, especially about the Nun's Cave, which has been hollowed out in them.

The fossils of the Pabba Shales of Carsaig were collected with much perseverance by the late Captain Bedford, while engaged in preparing the Admiralty Charts of these inaccessible shores. A list of species drawn up from his collections by Messrs. Davidson and Etheridge will be found in the Geologist, vol. v. p. 443.

The sandy representative of the Scalpa beds is, as at Duart, rather poor in fossils—*Pecten sublævis*, Phill., and *Gryphæa cymbium*, Lam., being, indeed, the only common forms. The rock here seems to be capable of furnishing a useful freestone. It was quarried for the famous edifices of Iona; and fresh supplies have recently been obtained for the repairs of those buildings. But for the inaccessibility of the rocky shores on which they are exposed, it is probable, indeed, that the beds would be extensively worked for building-purposes.

The exposures of the Middle Lias near Carsaig are of much interest, furnishing us, as they do, with the most southern exposure of the beds of that age in the Hebrides. Their equivalents next make their appearance as we pass southwards in the north of Ireland and in the outlier on the borders of Cheshire and Shropshire, though it is impossible to doubt that beds of this age have originally existed, and have been removed, by denudation, over a great part of the intervening area.

d. *The Upper Lias.*

As the beds of this age (owing to the faults by which the series of strata is there broken up) are nowhere exhibited in the Eastern Highlands, it is of particular interest to find them so clearly displayed, and presenting such an unmistakable and characteristic fauna, in the Hebrides. Lying, as they do, between the hard masses of the Scalpa Series below, and the Inferior Oolite above, the Upper Lias beds are almost everywhere covered by heavy taluses of fallen blocks; and it is not to be wondered at that Murchison, failing to recognize their existence, massed the strata of Middle Lias with those of the Inferior Oolite. To Messrs. Bryce and Tate we are indebted for first pointing out the existence of the Upper Lias formation in Skye—though even they appear to have failed to detect proof of its existence in the neighbouring island of Raasay. During my study of the district, I have found many evidences of the presence of this part of the Lias series, and have examined some interesting sections of its beds in both these islands, succeeding also in tracing deposits belonging to this geological horizon as far southwards as Ardnamurchan. In this last-mentioned district, however, the strata in question have suffered greatly from metamorphic action.

The Upper-Lias formation in the Western Highlands remarkably resembles both in the character and succession of its beds and its fossil remains the equivalent strata in England. In both districts we find the formation made up of laminated blue clays, containing argillaceous nodules, with much pyrites and jet in certain of its beds. This parallelism of the Scottish Upper Lias with that of England comes out in an even more striking manner when we study the distribution of organic remains in their several members. Thus, in the upper part of both we find an abundance of *Ammonites communis*, Sow., and similar forms, associated with *Posidonomya Bronni*, Voltz, and Belemnites, while at the base strata characterized by the abundance of *Ammonites serpentinus*, Rein., *Am. radians*, Rein., *Am. elegans*, Sow., and many other species of the group of the *Falciferi*, are equally distinctive of the beds.

The thickness of the Upper-Lias series in the Western Highlands is not very great. It averages perhaps from 75 to 80 feet, and occasionally, but rarely, reaches 100 feet. On the other hand, it is sometimes perhaps as little as 60 feet thick. Mr. Tate gives a measured section taken on the east side of Portree Harbour, which shows the Upper Lias as only 15 feet 7 inches thick; but as the section here is rendered somewhat difficult of interpretation through the numerous slipped masses, I have little doubt that the beds enumerated do not comprise the whole thickness of the formation at this point.

To Dr. Bryce and Professor Tate we are, as already mentioned, indebted for first pointing out the existence of the Upper Lias in Skye; but it seems to me, from a reexamination of their sections, that they have almost everywhere underestimated its thickness, having been betrayed into this mistake by the slipped condition of the beds in the great mural precipices and the interruption and confusion produced in the beds by the intrusive sheets of dolerite which are so numerous at the localities where the formation is exposed.

In Raasay the same strata are present, as I have been able to satisfy myself on several different occasions. Though certainly from 80 to 100 feet in thickness, they nowhere exhibit good sections, being almost always buried under talus from the beds above and also grass-covered.

Between Leac and Fearns, however, above the great development of the Scalpa Series, they consist of black laminated highly micaceous and ferruginous shales with *Belemnites Voltzii*, many Ammonites of the group of the *Falciferi*, such as *A. serpentinus*, Rein., *A. falcifer*, Sow., and *A. radians*, Rein., but all small and crushed, and some other shells. The same beds make their appeance, but even more obscurely, further to the north, in the precipices of Screpidale.

The Upper-Lias strata are certainly present in the district of Strath in Skye, and most probably also in Ardnamurchan; but in both these areas the beds are so greatly metamorphosed as to be only recognizable by their relations to the Middle Lias and Inferior Oolite respectively. In Mull they have nowhere been detected, the older strata being everywhere overlapped by the Cretaceous rocks.

e. *The Lower Oolite.*

The series of strata representing this formation in the Western Highlands is of very considerable thickness and importance. Rocks of this age must, indeed, have originally had a very wide distribution; for traces of them are found at various points, from the Shiant Isles in the north to Ardnamurchan in the south. The best exposures of their strata, however, are those which occur in the Islands of Skye and Raasay, in the sections so well described by Sir Roderick Murchison, and afterwards in greater detail by the late Dr. Bryce and Mr. Tate.

The Inferior Oolite, where best developed in the Western Isles, has a thickness of probably not less than 400 feet. An exact estimate of the dimensions of the whole formation and of the proportions of its several members is, however, rendered difficult owing to the manner in which the numerous intrusive sheets of Tertiary dolerite are interspersed through the series, and interrupt the continuity even of its best sections. The formation may be defined as consisting of the following members, proceeding from above downwards:—

	feet.
I. Limestones, almost wholly made up of comminuted shells, and resembling in their mineral characters the English Cornbrash and Forest Marble, with which formations they were identified by Sir Roderick Murchison	45
II. Beds of white sandstone, with some subordinate shaly bands, the whole containing much carbonaceous matter and some plant-remains, including both Ferns and Cycads	60
III. Alternating beds of sandstone and shale, the sandstone being usually calciferous, and containing great spherical concretions, and sometimes passing into shelly limestones. Marine fossils occur in these beds, but are by no means common, except in the highest of them, which abounds in Belemnites of several species. Ferns, Cycads, wood, and plant-remains of various kinds occur throughout the whole series	160
IV. Sandy micaceous shales, alternating with calciferous sandstones, the latter containing numerous spherical concretions and exhibiting mamillated surfaces. There are also some bands of shelly limestone in the series. Fossils, all of which are of marine forms, abound in these beds	120

With respect to the correlation of these different members of the Lower Oolite, it may be remarked that the division I., although made up of fragments of shells, seldom contains specimens in a sufficiently perfect state of preservation to permit of their specific determination. No Cephalopods have been found in this part of the series; and the few species of Lamellibranchiata and Brachiopoda which it has yielded, though all of Lower Oolite age, are not sufficient to enable us to state absolutely whether the bed should be regarded as belonging to the Great or to the Inferior Oolite series.

The division II. is probably of estuarine origin, and there is no direct palæontological evidence concerning its exact position in the geological series. It is clear, however, that it is on the same horizon with one or other of the Lower-Oolite Estuarine series of the English Midland Counties or of Yorkshire.

The division III. yields a considerable number of fossils, Belemnites of several species, *B. giganteus*, Schloth., and *B. aalensis*, Voltz, especially, being particularly abundant; and with these there occur specimens of *Ammonites Humphriesianus*, Sow., and of several of its varieties, such as *A. Blagdeni*, Sow., and *A. coronatus*, Ziet. A few other marine fossils, with some plant-remains, also occur at this horizon, which clearly represents the Zone of *Ammonites Humphriesianus*.

The division IV. is much richer in fossils than any of the higher members of the Lower Oolite, *Ammonites Murchisonæ*, Sow. (first described from a specimen obtained on the coast of Trotternish, near the islet of Holm), is particularly abundant throughout the division; and with the normal type of this species there occur many of the varietal forms, such as *Am. corrugatus*, Sow., *Am. læviusculus*, Sow., &c. A number of species of Belemnites also occur with some well-known Inferior-Oolite Lamellibranchiates and Brachiopods. It is clear, from the nature of its fauna, that this division must be assigned to the Zone of *Ammonites Murchisonæ*.

In the lowest part of the Lower-Oolite series of the Western Highlands I have detected a few fossils which seem to indicate the existence of a representative of the Midford Sand of England, and constitute a transition series into the Upper-Lias beds beneath. The horizon is not by any means well marked, and the very characteristic forms of Ammonites are, so far as I have been able to determine, wholly wanting in it.

Taken altogether, the Lower-Oolite strata of Skye, which are so well exhibited in their entirety in the fine cliff-sections above Prince Charles's Cave and the Holm Islet, and of which numerous partial exposures occur at the Beal, Scoribreck, and along the coast southward from Portree, may with great probability be regarded as representing both the Great and Inferior Oolite. But while it is quite certain that the divisions III. and IV. represent the lower part of the Inferior Oolite, some doubt still exists as to whether the divisions I. and II. should be regarded simply as the upper part of the Inferior Oolite, or as belonging in part to the Great Oolite also.

In the island of Raasay the Lower-Oolite beds appear in great force, but are exposed only in a series of vertical cliffs, which are almost everywhere perfectly inaccessible. From a comparison of the points at which the several members (which agree very closely in character with the strata already described in Skye) make their appearance, and a knowledge of the heights of certain points in the cliffs, we are able to appreciate how very grand is the development of the Lower-Oolite formation in these fine mural precipices of Raasay.

The estuarine conditions which prevail in the division II. of the Skye section are equally well marked in the equivalent beds in Raasay, and appear to extend down through a great part of the division III.; in this island, indeed, a thin seam of coal has been found in one place at the horizon in question. In this part of the series the strata appear to have even a greater thickness in Raasay than in Skye. The lowest division (IV.), too, appears to exhibit more littoral conditions in Raasay than in Skye, the sandy micaceous shales being less predominant, while coarse sandstones and grits with calcareous concretions full of shells take their place.

The Lower-Oolite strata appear to occur as far to the northwards as the Shiant Isles; for in a visit which I paid to that isolated group of rocky islets in company with Dr. Taylor Smith I found masses of greatly altered shale enclosed between gigantic intrusive sheets of coarse dolerite, as described on a previous page (see p. 677). The intense metamorphism to which these shales had evidently been subjected had resulted in converting highly micaceous clays, in places becoming sandy and calcareous, into hard masses like Lydian stone, and in other cases causing them to pass into a remarkable rock with a pseudo-pisolitic structure developed in its midst. For a long time we searched in vain for any traces of fossils other than those recorded by Macculloch as occurring here, namely the hollow casts of Belemnites; but at last we were so fortunate as to detect flattened impressions of Ammonites, which I was able to identify as *Am. Murchisonæ*, Sow., and *Am. corrugatus*, Sow. The forms of the Belemnite-casts, too, are in some cases undoubtedly those of *Bel. giganteus*; so that I have little hesitation in affirming that in these most remote representatives of the Jurassic system in the Hebrides we have the lowest part of the Inferior-Oolite series. In the district of Strathaird beds of Inferior Oolite occur immediately beneath the great capping of basaltic lava; but here the amount of alteration which the beds have undergone, owing to their proximity to the axis of the great Skye volcano, is very great indeed, and only at a few points have I been able to detect obscure traces of the characteristic fossils of this horizon. Their relations to the underlying strata are, however, perfectly clear and unmistakable.

Still further south, in Ardnamurchan, the Inferior-Oolite strata again make their appearance, and, indeed, occupy a considerable area; but here, as in Strathaird and the Shiant Isles, they have undergone great alteration. They are frequently, indeed, found to be intersected by such a plexus of veins and dykes of igneous rock as to have lost all traces of stratification and every vestige of fossils; but by tracing these masses over a considerable distance, less altered patches may sometimes be found; and in such I have detected such characteristic fossils as *Ammonites Murchisonæ*, Sow., *Belemnites giganteus*, Schloth., *Rhynchonella spinosa*, Schloth., and several other well-known Inferior-Oolite forms.

Still further south the Inferior-Oolite strata are entirely cut off by the overlap of the Upper Cretaceous.

The thickness of strata of Inferior-Oolite age exposed in the Shiant Isles does not appear to be very great. There are evidently beds of somewhat different mineral characters exposed there, some being more calcareous, others more argillaceous in composition. Most of the beds were, however, originally clearly arenaceous in character; but all have undergone great metamorphism through being entangled in the great sheets of basaltic rock already described (see section, fig. 6, p. 677).

The various sections in Skye and Raasay have been so fully described, first by Sir Roderick Murchison and afterwards by Dr. Bryce and Prof. Tate, that it is not necessary to dwell further upon the details exhibited by them. Locally they often exhibit a considerable amount of metamorphism resulting from the action of the numerous sheets and dykes of dolerite by which they are traversed. The beds display in an eminent degree the character so frequently exhibited by strata of littoral origin, and undergo great variations in thickness and mineral character within very short distances.

The greatly altered Inferior-Oolite strata of Strathaird are incapable of throwing any new light on the general characters, order of succession, or fossil contents of this formation. Their true position in the geological series is, indeed, only rendered manifest by a study of their relations to the Upper- and Middle-Lias strata.

The Inferior-Oolite strata of Ardnamurchan are only one degree less metamorphosed than those of Skye; but by carefully examining some portions of the beds which have undergone less intense alteration, we may, as already mentioned, detect here and there a fossil enabling us to decide on the age of the beds.

Southward from Ardnamurchan no traces of the Inferior-Oolite strata have escaped being swept away by denudation till we reach the well-known development of the formation in Yorkshire, where they exhibit estuarine characters somewhat similar to those which distinguish their Scottish equivalents.

Similar estuarine conditions characterize the beds of the same age in the place of their most northerly development in Britain, namely Sutherland; and in fact purely marine representatives of the formation are found only in the extreme southern portions of our island. The formation is excessively variable in its thickness in different areas, and over large portions of the British islands it is probable that no beds of this age were deposited at all. But it is no less clear that the few fragments left of its strata afford but very imperfect indications of the extent of country over which it was originally deposited, extensive denudation both prior to the Cretaceous and subsequently to the Miocene having effected so much in the destruction of the deposits of this period.

f. *The Great Estuarine Series.*

Beneath marine strata of Oxfordian age in the Eastern Highlands there occur, as we have shown in the first part of this memoir, a series of estuarine strata which contain the famous coal-seam of Brora. In a somewhat analogous position in the Jurassic series of the western coast similar estuarine beds also make their appearance.

As we have already shown in the foregoing pages, the Lower Oolites of the Hebrides include certain beds which exhibit evidence of having been accumulated under littoral, occasionally passing into freshwater conditions. But strata of far more pronounced estuarine characters succeed the Lower Oolites of the Western Isles, and are intercalated between them and the representative of the Oxford

Clay. In Skye and Raasay these strata, which are probably not less than 400 or 500 feet in thickness, are very imperfectly exposed; but southwards, in the islands of Eigg and Muck, the series acquires far greater proportions, and its characters are capable of being much more accurately studied.

The estuarine strata of Jurassic age in the Western Highlands present, like those of the eastern coast of Scotland, two distinct types, the arenaceous and the argillo-calcareous; the former closely resembling in characters the English Hastings Sand, the latter presenting the most striking analogy in their general features with our Purbeck and Punfield series.

The Great Estuarine Series is best displayed along the north-west shore of the island of Eigg, from Sgor Scalleadh to Laig Bay. The divisions which can here be recognized, proceeding from above downwards, are as follows:—

	feet.
I. Strata of black shale, crowded in places with *Cypris*, and alternating with thin bands of argillaceous limestone. They are sometimes crowded with *Cyrena* and *Cyclas*; but at others are full of *Paludina*, *Melania*, and other univalves. Beds, sometimes of great thickness, completely made up of the shells of *Ostrea hebridica*, Forbes, sometimes occur in the series, and these very closely resemble the Cinder-beds of the Purbeck series. Bands of fibrous carbonate of lime, like the "beef" and "bacon" bands of the same formation, also occur, and fish-remains, including both scales and teeth, are sometimes abundant	150
II. A great series of sandstone beds of white and grey tints, in places becoming very coarse-grained and passing into grits; occasionally, indeed, pebbles of white quartz become so numerous as to convert the rock into a conglomerate. These strata often exhibit much false-bedding, and their surfaces are sometimes found to be covered with ripple-marks, sun-cracks, and worm-tracks. In certain parts of the series the rocks contain a considerable quantity of carbonate of lime, and pass into calcareous grits. Thin coal-seams also occur in it. With the exception of plant-remains, which are at times found in a vertical position, the only fossils yet detected in this division are a few casts of *Cyclas*, and some other shells too imperfect for identification. A very striking feature often presented by the beds of this division is that the calcareo-siliceous rock contains great concretionary spheres, often many feet or yards in diameter; and striking mamillated and botryoidal forms also occur in it*. Owing to numerous and sudden changes in dip, the occurrence of frequent faults, and the interruption occasioned by intrusive sheets of dolerite, it is difficult to estimate the exact thickness of this series, but it would appear to certainly exceed	500
III. Laminated black shales and limestones like those of I., abounding in *Cypris* and fish-remains, and shells of *Cyrena*, *Cyclas*, *Paludina*, &c. Towards the base of the series beds of conglomerate and shelly limestone occur, which abound with freshwater shells, and also contain very numerous fish and reptilian remains, including remains of *Plesiosaurus*, Chelonians, &c.	200

* Hugh Miller first noticed and described a peculiar property which the sands formed by the disintegration of these beds exhibit, namely, that of giving forth a musical note when pressed by the feet in walking over them.

In the northern part of the area we are describing, as in Skye and Raasay, only the divisions I. and II. occur, III. being wholly wanting, or, as is not improbable, represented by the more purely marine beds I. of the Inferior Oolite. The uppermost division of the Loch-Staffin beds, first described by Macculloch, was referred by Murchison, on account of the peculiar characters of its beds and the general facies of its fossils, to the Wealden; and its true position in the geological series, as underlying strata containing Oxfordian fossils, was first shown by Edward Forbes in 1851*.

These same strata can also be traced lying at the top of the whole series of Secondary strata both in Skye and Raasay. In the former island they are seen not only in the mural cliffs on the east side of the Trotternish peninsula, but extend some distance inland, and are exposed by the denudation of the overlying basaltic lavas around Lochs Leithan and Fada, as pointed out by the late Dr. Bryce. They again make their appearance, but at much lower levels, at other points around the Trotternish peninsula, as at Aird and Duntulm; but in all these cases the strata have undergone great changes owing to the intrusion into their midst, during Tertiary times, of great masses of igneous rock. Thus the sandy beds are found converted into chert and quartzite, the clays into a hard and brittle material, breaking with a conchoidal fracture, and resembling Lydian stone, and the limestones into saccharoid marble. Further west in Skye, in the peninsulas of Vaternish and Quirinish, strata belonging to this part of the series are exposed on the coast, where they are seen lying under the thick series of Miocene lavas at Stein in Loch Bay, and at Copnahow Head. These exposures are interesting, as showing how widely spread is the great foundation of Secondary rocks lying beneath the Miocene basalts which cover all the northern part of the island of Skye.

In the island of Raasay the Great Estuarine Series is presented to us with a series of relations remarkably parallel with those which prevail in Skye. On the eastern coast the strata in question are seen at a great elevation, occupying, indeed, the highest crest of the island immediately below the isolated cap of basaltic lavas of Dun Can, by which they have been saved from the destructive action of the denuding forces. The same strata, however, are found rapidly dipping westward, and pass under the sea-level along the east shores of the Sound of Raasay, which must hence be traversed by a great fault with a throw of something like 1000 feet.

Passing from the northern to the southern area, it is in the latter, as we have already seen, that the strata of the Great Estuarine Series acquire their most important development. This is well illustrated by the sections in the islands of Eigg and Muck. In the former we, in the north-western part of the island, have a tolerably continuous section of the whole of the strata, though the base is unfortunately concealed beneath the sea-level. The same beds appear on the eastern side of that island, but are there rendered obscure by

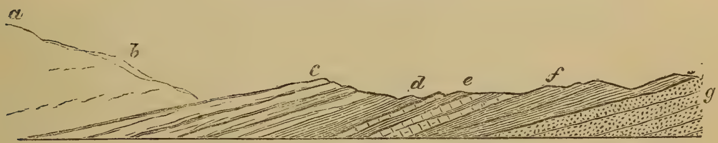
* Quart. Journ. Geol. Soc. vol. vii. p. 104.

the slipped masses of the overlying basalts. The upper divisions I. and II. resemble the equivalent strata of Skye and Raasay, but appear to have a somewhat greater thickness; while the lowest member, III., not represented in the northern localities, has in the southern area great thickness and importance.

The upper argillaceous series, which is fairly well exposed in Eigg, but much better in Muck, contains, as in Skye and Raasay, thick beds of dwarfed oysters (*O. hebridica*, Forbes), indicating a gradual transition into the marine Oxfordian beds above. Both in the northern and southern areas the argillaceous and arenaceous divisions of the Great Estuarine Series exhibit—as is so constantly the case with formations of this character—rapid and sudden changes in composition and thickness within very short distances.

The most southern exposure of the strata of this formation which is certainly known occurs in the island of Muck; and, as it has not been before described, I add a few notes on the section.

Fig. 9.—*Section exposed in reefs seen at low water at Camus Mhor, in the Island of Muck.*



a. Grass-covered slopes. *b.* Shingle.
c. Great bed composed of shells of *Ostrea hebridica*, Forbes.
d. Laminated shales, with bands of hydraulic limestone.
e. Oyster bands, with alternating limestones and shales.
f. Shales and limestone containing *Cyclas*, fish-remains, &c.
g. Calciferous sandstone (the lowest bed exposed).

The strata in question occur at the head of the little bay of Camus Mhor on the south side of the island, and consist of a number of beds forming reefs along the shore, with a dip inland of 5° (see fig. 9). These strata, of which probably the thickness exposed is not more than 20 or 30 feet, consist of thick masses of oysters intercalated with shale and limestone bands about 8 feet thick, lying upon beds of shale and limestone containing *Cyclas*, *Cyrena*, and some univalves. The lowest beds seen are somewhat more sandy in character. It is clear that all the beds of Camus Mhor in Muck belong to the division I. of the Great Estuarine Series, and it is not improbable that under the green slopes and shingle of the shore above traces of the overlying Oxford-Clay strata might be found.

It is quite possible that among the greatly altered rocks lying in close proximity to the gabbro-masses of the volcanic axis of Ardnamurchan the Great Estuarine Series may be represented; but that such is actually the case I have not been able to obtain any clear and unmistakable evidence.

These estuarine strata, so conspicuously exposed in Sutherland

and the northern part of the Inner Hebrides, must have originally constituted a great formation comparable to the Wealden of the south-east of England in the thickness of its strata and the area which it covered. Like the Wealden, too, it was only developed over a somewhat limited area, being due to conditions that could not be expected to extend far. Hence the purely Estuarine infra-Oxfordian delta must be regarded, like its Neocomian analogue, as constituting an entirely local and exceptional phenomenon. And, though the fragments preserved to us by such remarkable accidents, both on the east and west coasts of Scotland, can only be regarded as forming a series of very minute vestiges of this great formation, we must bear in mind that in the southern part of the British area it was represented by strata of much less thickness, which were almost uniformly of *marine* origin.

It is, however, worthy of remark that it is where the Great Estuarine Series attains its greatest thickness and fullest development that it is suddenly cut off by the overlap of the Upper-Cretaceous rocks.

g. *The Oxford Clay.*

Immediately overlying the great series of estuarine strata just described, we find, both in Skye and Eigg, a mass of blue clays containing some subordinate bands of argillaceous limestone, which are undoubtedly of marine origin. The age of this set of clays is fortunately placed beyond doubt by the nature of the fossils which they yield; for these clearly represent the fauna of the middle portion of the Oxford Clay—the zone of *Ammonites cordatus*.

The fossils of these strata, which are tolerably numerous, but by no means well preserved, have been examined by Prof. Ed. Forbes, who gives a list of the forms obtained by himself from Loch Staffin; and by Mr. Tate, who enumerates those found by Dr. Bryce at Uig. It will be interesting to give, for comparison with these, the following list of species, collected either by myself or Mr. Hugh Miller at the Bay of Laig, in the island of Eigg:—

Fossils of the Oxford-Clay Beds from the Bay of Laig, Island of Eigg.

Belemnites sulcatus, *Mill.*
—— gracilis, *Phill.*
Ammonites Williamsoni, *Phill.* (=A. arduennensis, *D' Orb.*).
—— Toucasianus, *D' Orb.*
—— cordatus, *Sow.* (Several varieties of this species are very abundant.)
—— excavatus, *Sow.*
—— Mariæ, *D' Orb.*
—— Lamberti, *Sow.*
—— Sutherlandiæ, *Sow.* Young forms.
Ostrea Rœmeri, *Quenst.*
Avicula expansa, *Phill.*
—— braamburiensis, *Sow.*
Arca, ? sp.
Nucua, sp.
Lucina, ? sp.
Astarte (near A. minima, *Phill.*).
Serpula.
Dorsal spine of fish.
Wood and vegetable remains abundant.

The Oxford-Clay strata of the Western Isles are nowhere well developed, nor do they at any point in the area exhibit clear or continuous sections. They appear to consist of dark blue shales, perfectly similar in character to the Oxford Clay of England, and containing septarian nodules, masses of pyrites, and occasionally much wood in the form of jet. At some localities they include irregular bands of argillaceous limestone.

Although so imperfectly exposed, it is clear, from the nature and position of the fragments of the formation which are seen, that beds of this age must underlie great tracts of the Miocene basalts of the Hebrides. The strata, too, are not improbably of very considerable thickness, although the slipping of the basaltic masses over them wherever they make their appearance prevents us from making any approach to an estimate of that thickness.

It is, indeed, to this slipping of the great masses of columnar and massive lava rocks upon the insecure foundation of the Oxford Clay that the striking scenery of the eastern side of the Trotternish peninsula, so well exemplified by the Quiraing and the Storr rocks, owes its origin. Here the Oxford Clay appears at great elevations, its fossils being collected occasionally during drainage-operations; while westward it dips away like the underlying estuarine beds, and disappears beneath the sea-level. Traces of it, however, are found at Duntulm, Mugstock, Uig, and some other points.

In Eigg, at Laig Bay, the same beds, with precisely similar characters and fossils, occur, but are only exposed at a few points along the shore at low water; they can only be satisfactorily examined during spring-tides. Possibly, although concealed by shingle and vegetation, a trace of the same set of strata occurs in the neighbouring island of Muck. To the southward, however, no traces of the formation have been detected.

Although the Oxford-Clay strata of the Western Highlands are so strikingly similar in character to those of England, the beds on which they repose are, as we have seen, of entirely different character. With respect to the question of the strata which may have been deposited above these Oxfordian rocks of the Hebrides, I will only refer to what I have already said as to the unreliability of the negative evidence in this case, and to the possibility, if not the probability, of rocks of Upper-Oolite and Neocomian age having originally existed in the Western as well as in the Eastern Highlands.

The Oxford Clay of both Scotland and England must have been deposited in a sea of considerable depth; and it is probable that its beds originally extended over a great part, at least, of what is now the area of the British Islands. Indeed, so strikingly similar is the formation in its mineral characters and the succession of its forms of life over the greater portion of the Anglo-Germanic area, that there can be no doubt as to the Oxfordian sea of that life-province being of very wide extent, as well as of considerable depth, and not broken up into a number of isolated portions. We find, however, in Yorkshire and elsewhere, indications of the prevalence of more littoral conditions, proving probably that some islands rose above the surface of this great Oxfordian sea. The position and relations of these, so far as they can be now ascertained, I hope to discuss on a future occasion.

D. The Cretaceous System.

The Cretaceous strata of the Western Highlands, although of no great thickness, are of surpassing interest. The fact of their presence in the area in question is one which, as we have already pointed out, is full of significance to the geologist who seeks to realize the vastness of the changes in physical geography of the Highland districts which have taken place during successive geological periods. But when the peculiar and anomalous character presented by these beds in the Scottish area comes to be fully appreciated, their important bearing on many great questions of theoretical geology must be apparent to every one; and the suggestiveness of the facts is enhanced when we compare the Scottish Cretaceous beds with their equivalents in other parts of Northern Europe and America.

As we have already pointed out, no vestiges of Neocomian strata have as yet been found in any part of the Western Highlands; but we have sufficiently insisted on the danger of accepting the negative evidence as being conclusive against such strata having ever been deposited within the district. From a careful consideration of all the facts of the case, I believe there are strong grounds for the presumption that very large areas in the Highlands were once covered by strata of Upper-Oolite and Neocomian age, the former being certainly represented by deposits of great thickness and importance.

The Upper Cretaceous strata, though represented at the present day by such minute and inconspicuous patches, must once have had a wide range, and in places probably attained a considerable thickness. It is clear, from the abundance of chalk-flints in certain Miocene inter-volcanic deposits, such as those of Ardtun and the Innimore of Carsaig, that very extensive masses of Chalk must have been destroyed by denudation in order to supply the quantities of flints accumulated in those deposits. It is probable, indeed, that very considerable masses of strata of Cretaceous age still exist buried under the great lava plateaux of Mull and Morvern.

The Upper Cretaceous strata of the Western Highlands rest everywhere unconformably upon the older rocks. Thus at Carsaig they are seen reposing directly upon the Middle Lias; at Loch Aline they overlap successively the Lower Lias, the Infralias, and the Poikilitic; while at Gribun they appear to lie in part on Poikilitic strata, and in part on the old gneissic rocks, which are presumed to be of Lower Silurian age.

The succession of deposits belonging to the Upper Cretaceous in the district of the Western Highlands is very peculiar; for we there find the strata of this age assuming those littoral and estuarine conditions which are so strikingly exhibited by the underlying Jurassic beds. As might be expected under such circumstances, the Cretaceous beds exhibit very rapid and remarkable changes in thickness and character even within exceedingly short distances. The strata represented may be exhibited in a tabular form as follows, proceeding from above downwards :—

		feet.
I.	Sandstones and white marls, with numerous plant-remains and occasional thin seams of coal. The Miocene basalts and volcanic tuffs are seen to repose upon eroded surfaces of this set of beds. This series is nowhere exposed in a section of more than 20 feet; but what its full thickness may have originally been, we have no means of judging	20
II.	Beds of white indurated Chalk with bands of flints. The Chalk itself is usually converted into an almost purely siliceous rock, the various minute organisms in it, however, being still recognizable. The fossils in these beds are all marine. Though no section more than 10 feet in thickness of these beds can be anywhere seen, yet it is evident that in places they must have attained a very considerable development. Only here and there, however, can they be traced, where some fortunate accident has exposed the base of the great superincumbent masses of basaltic lava............	10+
III.	Beds of white sandstone, without fossils, occasionally containing many white quartz pebbles, and passing into conglomerate. These beds have yielded no vestiges of marine life, but in places contain much carbonaceous matter, and at one point a seam of coal has been detected in their midst. Their thickness is very variable, averaging about	100
IV.	Glauconite sandstone (greensand). Often highly calcareous in its upper part and passing into limestone, but still containing the characteristic grains of glauconite. At other points it passes into an areno-argillaceous rock of a dark green colour, very similar in appearance to portions of the Hibernian Greensand. The fossils in these beds are very numerous and entirely of marine forms; although individuals are so abundant, however, the number of species is by no means very great. The thickness of this marine series is very variable, the maximum may be taken at	60

We thus see that the Upper-Cretaceous series in the Western Highlands consist of four members, two marine and two estuarine. The exact age of the marine strata can be fixed precisely by the fossils which they contain, that of the estuarine beds can only be inferred from their relations to the marine series.

The lowest series of beds (IV.) unquestionably represents the Cenomanian or Upper Greensand, and in its mineral characters greatly resembles the equivalent strata in England and Ireland. The fossils which it contains place this identification beyond doubt; they include the following species :—

Nautilus Deslongchampsianus, *D'Orb.*
Exogyra conica, *Sow.* (very abundant).
—— haliotoidea, *Sow.*
——, sp.
Pecten asper, *Lamk.*
Pecten orbicularis, *Mant.* (abundant).
—— quinquecostatus, *D'Orb.*
Serpula, sp.
——, sp.
Spongia paradoxa.

Unfortunately no Ammonites have been detected in the Scottish deposits; and it seems probable that the Upper Greensand of this northern area was deposited under more littoral conditions than the strata of the same age in England.

The series II. contains *Belemnitella mucronata*, Schloth., with a coral and many fragments of *Inoceramus*. Its age is clearly the same as that of the greater part of the White Limestone of Ireland and of the highest beds of Chalk in England.

The Estuarine series (III.) may be fairly regarded as representing the whole or a portion of the Chalk series intervening between the Upper Greensand on the one hand, and the Chalk with *Belemnitella mucronata* on the other.

The age of the Upper Estuarine series (I.) is more doubtful. It appears to be so closely connected with the series below, that I am strongly inclined to regard it as of Cretaceous age, and either as representing one of the higher members of the Chalk (the Faxoe or Meudon beds) not elsewhere developed in this country, or as deposited in the interval between the Cretaceous and Eocene periods. But it is by no means impossible that future research may demonstrate these beds to belong to the Tertiary and to be of Eocene or even later date.

Thus we have arrived at the conclusion that while the series IV. represents the Upper Greensand; III., II., and I. must in all probability be regarded as constituting an abnormal development of the English Chalk. It will be convenient to discuss the characters of these two sets of deposits separately.

In the northern portion of the Western Highlands no trace of the Cretaceous strata has yet been detected; and, indeed, the whole of the strata show a tendency to thin out in that direction. We must not, however, overlook the possibility that beds of this age may once have existed there and have been wholly removed by denudation; and this caution will more especially appear to be necessary when we remember the deposits of chalk-flint in Aberdeenshire, which seem to prove the extension of the Cretaceous ocean in that direction.

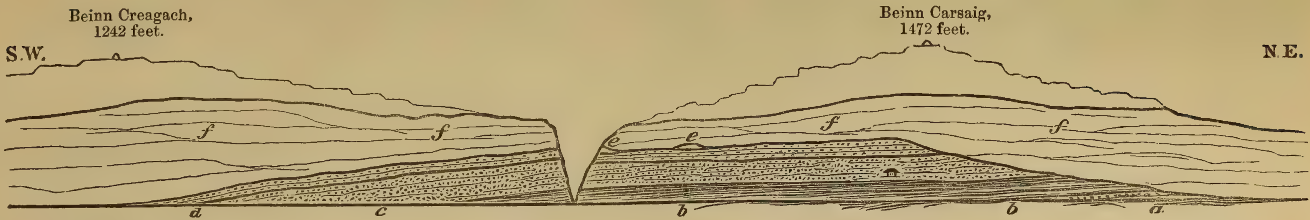
a. *The Upper Greensand and associated Beds.*

Perhaps the best exposures of the Upper-Greensand strata are those which occur about Carsaig, on the south side of the island of Mull; and it is here that I first detected the presence of beds of this age in 1872.

Above Carsaig House, and in the midst of woods that clothe the precipices which shelter this beautiful spot, there is an old quarry, from which, when the house was originally built, masses of stone were thrown down for burning into lime. This stone is found to be crowded with fossils of the Upper Greensand, *Exogyra conica* occurring in the greatest profusion, and *Pecten orbicularis* being by no means rare.

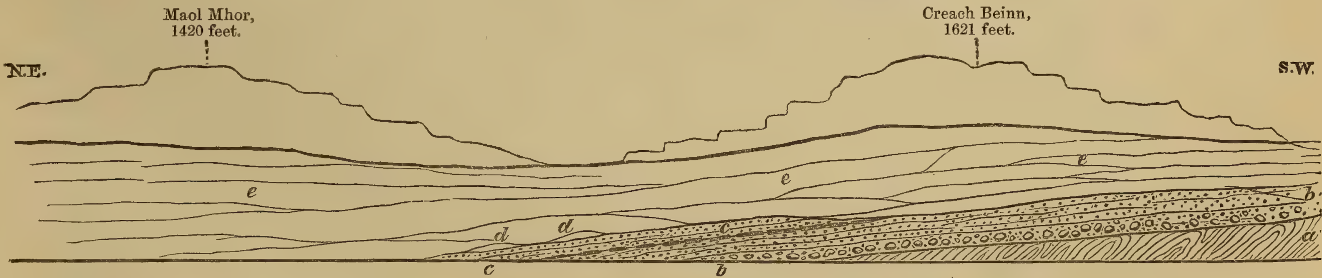
The section here is by no means clear or well exposed. At two separate points I have detected masses of the altered chalk- and flint-beds squeezed out from beneath the mass of superincumbent basalt; but further than the fact that these beds overlie the Greensand, it is impossible to obtain any light on the true relations of the members of the Cretaceous series here. The section (fig. 10) shows the general relations of the beds exposed in the cliffs at Carsaig.

Fig. 10.—*Generalized Section of the Strata exposed at Carsaig, on the South shore of the Isle of Mull.*



a. Lower-Lias shales and limestones, forming reefs on the shore.
b. Pabba Shales, with many fossils, exposed at low water.
c. Sands representative of the Scalpa Series (few fossils).
d. Upper Greensand, in part calcareous (numerous fossils), with estuarine sandstone above.
e. Upper chalk (silicified), only imperfectly exposed.
f. Miocene basaltic lavas and tuffs.

Fig. 11.—*Generalized Section at Gribun, Isle of Mull.*



a. Gneiss, quartzite, and quartz-schist.
b. Poikilitic breccias, conglomerates, and sandstones.
c. Upper-Greensand conglomerates and sandstone.
d. White Chalk and flint (very imperfectly exposed), with traces of the estuarine sandstone below.
e. Tertiary lavas and tuffs.

The Upper Greensand itself appears to consist of two portions, the higher calcareous, the lower arenaceous. The calcareous beds derive their character from being almost wholly made up of shells of *Exogyra conica*, and are in fact great oyster-banks. Both the calcareous and the arenaceous beds contain the characteristic grains of glauconite.

The Upper Greensand behind Carsaig House is found to rest directly upon the sandy strata of the Middle Lias (Scalpa Series). When traced westwards, however, the Greensand is found occupying gradually lower levels, owing to a dip in that direction, till at last it reaches the sea-level at a point beyond the celebrated Nun's Cave. Throughout the whole of its exposure on this coast the strata are crowded with *Exogyræ* and other shells ; but the beds of highly calcareous character appear to be somewhat local, and do not seem to occur at the westernmost exposures of the formation.

The next place at which the Upper-Greensand strata are exposed is about Loch Aline. Here the beds in question are found overlapping the Lower-Lias strata, and can be well studied on the shore along the western shores of the Loch, at a little distance above the inn and village. None of the strata are here so highly calcareous as above Carsaig House; but beds of dark green clayey sand occur at several points in the series. The fossils are abundant and of the same species as at Carsaig.

The Upper-Greensand strata presenting everywhere the same characters, but apparently diminishing in thickness as we go northwards, can be detected around the head of Loch Aline, about Loch Arienas, and, finally, in the remarkable outliers of Morvern, where the most northerly exposures of the beds of this age occur.

At Gribun on the shores of Loch-na-Kael and in the opposite islet of Inch Kenneth, the Upper Greensand makes its appearance and presents somewhat different features from those which characterize it at the localities already described. The strata there are found resting directly upon the Poikilitic beds already noticed, and, indeed, are largely formed of the materials derived from those beds. Under these circumstances it is not surprising that the line of division between the Cretaceous above and the Poikilitic below is often very obscure. While the upper part of the Greensand here consists of the ordinary glauconitic sands, in which I have detected the common *Exogyra conica*, species of *Serpulæ*, and *Spongia paradoxa*, the lower part consists of a conglomerate of quartzite pebbles derived directly or indirectly from the old gneissic rocks of the district, upon which the Poikilitic strata here rest. There are grounds, indeed, for believing that the Upper-Greensand strata here completely overlap the Poikilitic beds, and rest directly upon the old gneiss rocks themselves. At two or three points at Gribun the peculiar beds of the Scottish Chalk—here converted into a siliceous material—are seen crushed out from beneath the overwhelming masses of basaltic lava that cover all the Secondary strata to such a great depth at this place. The accompanying section (fig. 11, p. 731) illustrates the general relations of the beds seen at Gribun.

As affording indications of the existence of an old beach of the Cretaceous sea, these beds of Gribun and Inch Kenneth are of very great interest to the geologist; and, but for the occurrence of the characteristic fossils in their upper part, it would be impossible to discriminate the beds of pebbles which compose them from those of the underlying Poikilitic series, the reconstructed materials of which form so large a proportion of their mass.

b. *The Strata representing the Chalk.*

In speaking of the Upper-Greensand beds we have already had occasion to notice the small masses of altered Chalk at Carsaig and Gribun. Although converted into a siliceous rock, the fact that this chalk was originally calcareous (that is, made up of shells of Foraminifera, with fragments of *Inoceramus* and other organisms common in the English Chalk) is made perfectly clear by the study of thin sections of the rock by the aid of the microscope. In this examination of the Scottish Chalk, I have received much aid and many valuable suggestions from my friends Professors W. K. Parker and T. Rupert Jones. To the latter I am indebted for the note on the organisms occurring in a series of sections which I had prepared of these rocks, which is printed at the end of this paper (p. 739).

Although there are several other points in the island of Mull at which strata probably belonging to different parts of the Upper Cretaceous occur, yet at all these places the relations of the beds are so obscure, or their characters have been so completely modified by the influence of the great volcanic masses in their neighbourhood, that it would not be safe to pronounce with confidence on the age of any of them.

In Morvern, however, the characters and relations of the strata representing the Chalk can be more perfectly made out. On both sides of Loch Aline and along the south shore of Loch Arienas the Greensand strata are covered by thick masses of coarse white sandstone, locally assuming variegated tints. These contain no fossils, but from their stratigraphical relations can be safely correlated with the Middle and Lower Chalk of England. This mass of sandstone strata varies greatly in thickness and characters, but seldom, if ever, exceeds 100 feet. It contains no fossils, but exhibits evidence of having been accumulated under estuarine conditions.

The most interesting of all the sections of the representatives of the Chalk strata, however, are those which occur beneath the singular outlying masses of Beinn-y-Hun and Beinn-y-Hattan, in the same district of Morvern, where they are preserved by the singular accident already described. (See the section, Plate XXXI. fig. 2.) There are, however, only a few points along the lines of outcrop of these beds where the succession of strata can be satisfactorily made out.

In Beinn-y-Hun the masses of coarse estuarine Sandstone representing the Lower and Middle members of the Chalk are fairly well seen, and are probably nearly 100 feet in thickness. In the midst of these sandstones Macculloch found a thin seam of lignite or coal;

and I have been told by the shepherds who frequent the mountain, that such a seam of coal, two or three inches in thickness, is sometimes exposed after great falls have taken place from the sandstone cliffs. The surface of these sandstone strata in Beinn-y-Hattan has evidently been subjected to subaerial denudation before the Miocene basaltic lavas were poured out above them. In some cases the base of the lava-streams is seen to contain numerous angular fragments of the sandstone, which have been converted into a substance resembling quartzite; in other instances the surfaces of sandstone over which the lava has flowed have been broken up into hexagonal columns by the contraction of the mass in consequence of its being heated and desiccated. The Cretaceous strata of Beinn-y-Hun, like those seen in the cliffs on the opposite side of Lake Arienas, probably rest unconformably on Poikilitic marls, sandstones, and conglomerates; but owing to the quantities of talus at the base of the cliffs of Secondary strata, these rocks are very imperfectly exposed. The outlier of Secondary strata in Beinn-y-Hun, which is capped by a mass of Miocene basalts about 250 feet thick, is traversed by a considerable fault with a throw of from 300 to 400 feet, which appears to be parallel with the far greater fault which traverses the Innimore of Ardtornish, and limits the outlier of Beinn-y-Hattan on the east.

In Beinn-y-Hattan, which rises to the height of 2308 feet above the sea-level, the cap of Miocene basalts is much thicker than in Beinn-y-Hun, attaining to no less than 600 or 800 feet. The series of Secondary strata exposed below the basalts, too, is of far greater interest in the former mountain than in the latter. The nature and succession of these Secondary strata will be best illustrated by one or two detailed sections obtained at points where streams have cut through the masses of talus that usually obscure the cliffs formed by the softer Secondary rocks lying at the base of the great basaltic precipices that constitute the mountain-peak. The Secondary strata lie directly upon the old gneiss rocks, and the overlying basalts are evidently relics of great and wide-spreading lava-currents; they are frequently columnar, and alternate with tuffs, burnt soils, &c. The Secondary strata, both in Beinn-y-Hun and Beinn-y-Hattan, are traversed by numerous basaltic dykes; one of these on the latter mountain, consisting of horizontal columns, forms a very striking and beautiful object.

Section obtained at the east end of Beinn-y-Hattan, Morvern.

		ft.	in.
	1. Miocene basaltic lavas alternating with tuffs &c.		
	Beds of reddish-brown volcanic ash...... .... 15 to	20	
Upper estuarine series (a few feet only in thickness).	(*a*) Thin seam of lignite	0	2
	(*b*) Laminated greyish clay with much carbonaceous matter and many obscure plant-remains ....8 in. to	1	
	(*c*) Grey chalky bed, not constant, consisting of whitish marl with plant-remains, containing angular fragments of the underlying Chalk. This bed appears to afford evidence of the upheaval of the marine beds before its deposition ....0 to	1	6

		ft.
Upper Chalk.	(*d*) White Chalk converted into a siliceous rock, with flints. This rock abounds with fragments of *Inoceramus* and *Globigerinæ*. It has yielded also *Belemnitella mucronata*, Schloth. sp., and some other fossils in a very imperfect condition	3
	(*e*) Bed of argillaceous limestone, with many irregularly shaped nodules and glauconite grains	1 to 2
	This bed graduates down into	
	(*f*) Argillaceous greensand	4 to 5
	(These beds represent the zone of *Belemnitella mucronata*.)	
Estuarine Beds.	(*g*) Coarse white sand, with a few green grains in the upper part	10 to 12
	(This bed probably represents, in a greatly diminished condition, the lower of the two Cretaceous estuarine series.)	
Upper Greensand	(*h*) Bed of Greensand, becoming calcareous in places and crowded with *Exogyra conica*, Sow., *Pecten orbicularis*, Sow., and *Vermicularia* (several species), with other common Cenomanian fossils	1
	(*i*) Greenish argillaceous sand	5?
Lias.	(*k*) Blue-lias shales and limestones crowded with the usual fossils—*Gryphæa arcuata*, Lam., *Unicardium cardioides*, Phil. sp., *Lima pectinoides*, Sow. sp., *Cardinia Listeri*, Sow. sp., *Pentacrinus*, sp., &c.	6
	(Lower Lias.)	
Poikilitic.	(*l*) Variegated sands, marls, and concretionary limestone, with beds of grit and conglomerate, lie at the base of the series and rest on the old gneiss rocks, but are very imperfectly seen at this point.	

The total thickness of strata lying between the basalt above and the gneiss below in Beinn-y-Hattan is probably from 100 to 120 feet in thickness.

As showing the variation in thickness and character of the beds at short distances, I may cite another section taken at a point not far removed from the last:—

	ft.	in.
1. Basalt lava, scoriaceous at its base.		
Bed of indurated reddish-brown volcanic ash	10 to 12	
(*a*) Thin coal-seam		1 to 2
(*b*) Underclay	6 in. to 1	
(*c*) White, highly siliceous chalk with flints	3	
(*d*) Sandy bed with glauconite grains and irregular concretionary nodules	3?	
(*e*) White coarse sand	15?	

Beneath the last bed the representatives of the Upper Greensand, the Lower Lias, and the Poikilitic can be certainly made out; but the sections are too obscure to enable us to estimate the thickness of the several beds.

Another interesting section of the Secondary strata is found at the south-east angle of Beinn-y-Hattan, where the succession of beds is as follows:—

	Miocene Basalts.	ft.	in.
Upper estuarine series, 4 ft. 6 in.	(*a*) Thin seam of grey marl	0	1
	(*b*) Black carbonaceous and micaceous sand	0	3
	(*c*) Brown micaceous sand, passing down into white and grey sand of a coarse character. Many carbonaceous markings	3	0
	(*d*) Whitish grey marl with plant-remains	1	0
	(*e*) Laminated grey marl with seam of impure lignite	0	2
Chalk.	(*f*) Band of weathered chalk-flints	1	0
	(*g*) White highly-siliceous chalk (only imperfectly exposed here)	3	0?
Lower estuarine.	(*h*) Sands (not well seen)	10	0?
	(*i*) Coarse white sands, becoming greenish and glauconitic at the base	20 to 30	0
Upper Greensand.	(*k*) Calcareous greensand with shells	0	6
	(*l*) Greensand with fossils	1	0
	(*m*) Dark green glauconitic sands crowded with shells	3	0
	(*n*) Calcareous greensand with several bands of shells	6	0
	(*o*) Glauconitic sands crowded with fossils	1	6
	(*p*) Greenish grey sand with many quartz-pebbles and much glauconite in its lower part	6	0
	(*q*) Grey sand, greenish and glauconitic in places	10	0
	(*r*) Hard calcareous band with a few fossils .... 6 in. to	1	0
	(*s*) Grey glauconitic sand	5	0
	(*t*) Beds of indurated greensand with only a few fossils	10	0

(Very strong springs arise at the base of this last bed.)

An abstract of the section at this point gives the following as the thicknesses of the several formations :—

(1)	Upper estuarine strata	4 ft. 6 in.
(2)	Upper Chalk (marine)	3 to 4 ft.
(3)	Lower estuarine strata	35 ft. ?
(4)	Upper Greensand	44 ft.

The Lower Lias and Poikilitic, which lie below the Cretaceous strata here, have probably a united thickness of about 50 feet.

The only locality, besides the outliers already described, in which I have found any traces of the Upper series of estuarine strata forming the top of the Cretaceous series is in a little glen to the southeast of Ardtornish Towers, which, from the fact that some two tons of impure lignite were once obtained from it, is known as "the Coal Glen." The section here is unfortunately very obscure indeed; and I could only determine the fact that the lignite-beds in question lie between the Miocene basalts and tuffs above, and red sands, clays, and concretionary limestones of the Poikilitic series below. It is possible, however, that if a more complete section were obtainable, the succession of strata would be found similar to that seen in Beinn-y-Hattan. The age of this upper series of estuarine beds must still be regarded as doubtful. From their apparent close connexion with the strata below, I am inclined to consider them as Cretaceous, and as representing beds younger than any part of the Chalk of the British islands; but it is quite possible that they may

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[To face p. 736.

TABLE ILLUSTRATING THE SUCCESSION OF SECONDARY STRATA IN THE WESTERN HIGHLANDS.

Formations.	Nature of the Beds.	Approximate Thickness.	Characteristic Fossils.	Localities.	Equivalents.
CHALK.	White marly and sandy beds, with thin seams of lignite.	feet. 20+	Plant-remains (species indeterminable).	Beinn-y-Hattan, The "Coal Glen"? } Morvern.	Maestricht and Meudon beds? or Eocene?
	White chalk (usually silicified), with flints.	10+	*Belemnitella mucronata*, Schloth.; *Inocerami*; Corals; Foraminifera; Sponge-spicules.	Carsaig; Gribun; Beinn-y-Hattan.	Zone of *Belemnitella mucronata*. Upper Chalk.
	Thick white sandstones (occasionally variegated) with some carbonaceous matter.	100	Obscure plant-markings.	Carsaig; Gribun; shores of Loch Aline; Beinn-y-Hun; and Beinn-y-Hattan.	Middle and Lower Chalk.
UPPER GREEN-SAND.	Glauconitic sands, with some beds of more argillaceous character, the whole occasionally assuming a calcareous character and passing into shelly limestones.	60	*Exogyra conica*, Sow.; *E. haliotoidea*, Lamk.; *Nautilus Deslongchampsiana*, D'Orb.; *Pecten asper*, Lamk.; *P. orbicularis*, Sow.; *Janira quinquecostatus*, Sow. sp.; *Serpula*, sp.; *Spongia paradoxa*.	Carsaig and the Innimore of Carsaig; Gribun; Inch Kenneth; Loch Aline; Beinn-y-Hun; Beinn-y-Hattan.	Upper Greensand. Cenomanian.
	GREAT UNCONFORMABLE BREAK.				
MIDDLE OXFORDIAN.	Dark blue clays, with septarian nodules and some irregular bands of argillaceous limestone.	? Very considerable.	*Belemnites sulcatus*, Mill.; *B. gracilis*, Phill.; *Ammonites cordatus*, Sow. (varieties); *A. Williamsoni*, Phil.; *A. Toucasianus*, D'Orb.; *Ostrea Römeri*, Quenst; *Avicula expansa*, Phil.; *A. Braamburiensis*, Sow.; vegetable remains.	Laig Bay; I. of Eigg; Loch Staffin; Mugstock; Uig Bay; Duntulm.	Middle Oxfordian.
GREAT ESTUARINE SERIES.	Alternating shales and shelly limestones, with bands of oysters and of fibrous carbonate of lime.	150	*Ostrea hebridica*, Forbes; *Corbula MacNeilli*, Mor.; *C. hebridica*, Forbes; *Mytilus cuneatus*, Sow.; *Trigonia tripartita*, Forbes; *Anomia æstuarina*, Tate; *Pholadomya acuticosta*, Sow.; *Perna Murchisonæ*, Forbes; *Nerita staffinensis*, Forbes; *N. arata*, Tate; *Hydrobia præcursor*, Sandb.; *H. caledonica*, Tate; *Cyrena Jamesoni*, Forbes; *C. Cunninghami*, Forbes; *C. Brycei*, Tate; *C. arata*, Forbes; *C. Maccullochii*, Forbes; *Estheria Murchisonæ*, T. R. Jones; Cyprids, Fish-remains, &c.	Camus Mhor; I of Muck; Laig Bay, I. of Eigg.	Lower Oxfordian and Great Oolite.
	Thick masses of white and grey sandstone, sometimes conglomeratic and occasionally calcareous; exhibiting globular concretions and mammillated surfaces with ripple- and fucoid-markings, &c.	500+	Wood- and plant-remains. Casts of *Cyclas* or *Cyrena*.	North-east and north-west shores of I. of Eigg; Screpidale, I. of Raasay; cliffs of Trotternish in Skye.	
	Laminated black shales and limestones, with bands of oysters and fibrous carbonate of lime.	200+	*Ostrea hebridica*, Forbes; *Cyclas*, sp.; *Cyrena*, sp.; *Estheria Murchisonæ*, T. R. Jones; Reptilian- and Fish-remains.	North end of I. of Eigg; Screpidale in I. of Raasay; cliffs of Trotternish in Skye; Lochs Leathan and Fada in Skye; Copnahow Head, Skye; Loch Bay, Skye.	
LOWER OOLITES.	Limestones almost wholly made up of comminuted shells.	45	*Ostrea Sowerbyi*, M. & L.; *Avicula contorta*, Sow.; *Lima gibbosa*, Sow.; *Terebratula lagenalis*, Sow.; *Rhynchonella concinna*, Sow.?		Inferior Oolite. Zone of *A. Parkinsoni*?
	Beds of white sandstone, with some thin shaly bands, and often containing much carbonaceous matter.	60	Remains of Ferns and Cycads.		?
	Alternating beds of sandstone and shale, the former containing great globular concretions and passing into shelly limestones.	160	*Belemnites giganteus*, Schloth.; *B. alensis*, Voltz; *Ammonites Humphriesianus*, Sow.; *A. Blagdeni*, Sow.; *A. coronatus*, Schloth.; *A. comensis*, Von Buch; *Pecten lens*, Sow.; *Pecten personatus*, Goldf.; *Terebratula perovalis*; *Rhynchonella concinna*.		Zone of *A. Humphriesianus*.
	Sandy micaceous shales alternating with calciferous sandstones, exhibiting globular concretions and mammillated surfaces.	120	*Belemnites giganteus*, B. sp.; *Ammonites Murchisonæ*, Sow.; *A. corrugatus*, Sow.; *A. læviusculus*, Sow.; *Lucina Wrightii*, Op.; *Avicula inæquivalvis*, Sow.; *Pleuromya jurassi*; *Ostrea*, sp.; *Cucullæa cancellata*; *Nucula Hammeri*, Defr.	Screpidale, I. of Raasay; cliffs of Trotternish, Skye; Tor Inivaig, Skye; Shiant Isles; Strathaird, Skye; Ardnamurchan.	Zone of *Ammonites Murchisonæ*.
UPPER LIAS.	Finely laminated blue clays, with argillaceous and pyritous nodules and some jet.	100	*Belemnites Voltzii*; *B. inornatus*; *Ammonites communis*, Sow.; *Am. radians*, Rein.; *Am. serpentinus*, Rein.; *Am. elegans*; *Am. bifrons*, Brug.; *A. heterophyllus*, Sow.; *Posidonomya Bronni*; *Inoceramus dubius*, Sow.	Screpidale, I. of Raasay; Fearns, Raasay; cliffs of Trotternish, Skye; Tor Inivaig, Skye; Strathaird, Skye.	Upper Lias Clay.
MIDDLE LIAS.	Calcareous sandstones highly micaceous, sometimes ferruginous, and at times becoming more or less argillaceous in character. In the southern area represented by soft greenish sandstone, with little calcareous matter.	200	*Belemnites elongatus*, Mill.; *Ammonites spinatus*, Brüg.; *A. margaritatus*, De Montf. (varieties); *Cryptænia expansa*, Sow. sp.; *Pholadomya ambigua*, Sow.; *Avicula inæquivalvis*, Sow.; *Lima Hermanni*, Voltz; *Pecten æquivalvis*, Sow.; *P. sublævis*, Phil.; *P. liasinus*, Nyst; *Plicatula spinosa*, Sow.; *P. lævigata*, D'Orb.; *Gryphæa gigantea*, Sow.; *Rhynchonella tetrahedra*, Sow.; *R. bidens*, Phill.; *R. acuta*, Sow.; *Terebratula resupinata*, Sow.; *T. punctata*, Sow.; *Pentacrinus*, &c.	South end of I. of Raasay; I. of Scalpa; Peninsula of Trotternish, Skye; Tor Inivaig, Skye; Strathaird, Skye; Ardnamurchan; Duart, I. of Mull; Carsaig, I. of Mull.	Zones of *Ammonites spinatus* and *A. margaritatus*.
	Dark-coloured micaceous shales, with many limestone nodules. In places the beds become more or less sandy in character.	200	*Belemnites elongatus*, Mill.; *B. paxillosus*; *Ammonites Jamesoni*, Sow.; *A. brevispina*, Sow.; *A. polymorphus*; *A. Davæi*, Sow.; *Chemnitzia Blainvillei*, Benz.; *Tectaria imbricata*, Sow. sp.; *Pholadomya decorata*; *P. ambigua*, Sow.; *Pleuromya ovata*, Röm.; *P. Scottica*, Wr.; *Unicardium Ianthe*, D'Orb.; *Pinna folium*, Y. & B.; *Mytilus scalprum*, Sow.; *Gryphæa cymbium*, Lam.; *Plicatula spinosa*, Sow.; *P. lævigata*, D'Orb., &c.	I. of Pabba; cliffs at Tor Inivaig; Leac, Raasay; Ardnamurchan; Duart, I. of Mull; Carsaig, I. of Mull.	Zone of *A. Jamesoni*.
	Similar dark-blue micaceous shales, crowded with fossils. (Sandstone beds in places.)	100?	*Ammonites armatus*, Sow.; *A. oxynotus*, Quenst.; *A. ibex*, Quenst.; *A. Valdani*, D'Orb.; *Leda complanata*, Phill. sp.; *Gryphæa obliqua*, Goldf.; *Plicatula spinosa*, Sow.; *P. lævigata*, D'Orb.; *Unicardum cardioides*, Phill. sp.; *Lima punctata*, Sow.	Hallaig, I. of Raasay; Tobermory; I. of Mull.	Zones of *Ammonites armatus*, *A. ibex*, and *A. oxynotus*.
LOWER LIAS.	Dark-coloured sandy and micaceous shales, with some bands of shelly limestone.	150	*Ammonites semicostatus*, Y. & B.; *A. Sauzeanus*, D'Orb.; *A. Brooki*, Quenst. (non Sow.); *Gryphæa arcuata*, Lamk, var.; *Lima gigantea*, var., Sow.	I. of Raasay; Obe Breakish, I. of Skye; Mingary; Ardnamurchan; Loch Aline, Morvern; Duart and Carsaig, I. of Mull.	Subzone of *Ammonites semicostatus*.
	Shelly limestones alternating with shales and crowded with fossils.	250	Enaliosaurian remains; *Ammonites Bucklandi*, Sow.; *A. Conybeari*, Sow.; *A. kridion*, Hehl; *Nautilus striatus*, Sow. sp.; *Cardinia Listeri*, Sow. sp.; *Myacites liasinus*, Röm.; *Pholadomya glabra*, Ag.; *Astarte dentilabrum*, Eth.; *Pinna Hartmanni*, Goldf.; *Lima gigantea*, Sow.; *L. succincta*, Schloth. sp.; *L. pectinoides*, Sow. sp; *Gryphæa arcuatus*, Lamk.; *Pecten textorius*, Schloth.; *P.*, sp.; *Pentacrinus tuberculatus*, Mill.; *P. briareus*, Mill.	Applecross; Hallaig, I. of Raasay; Obe Breakish, Skye; Strath in Skye; Surdil and Mingary, Ardnamurchan; Loch Aline, Morvern; Craignure, I. of Mull; Carsaig, I. of Mull.	Zone of *Ammonites Bucklandi*.
INFRA-LIAS.	Compact and oolitic limestones alternating with calcareous grits and conglomeratic sandstones, with occasional seams of coal and many carbonaceous markings.	400	*Ostrea irregularis*, Müust.; *Terquemia arietis*, Quenst. sp.; *Pinna*, sp.; *Lima*, sp.; *Phasianella*, sp.; Univalves; *Rhynchonella*, sp.; and many fragmentary fossils; Echinodermata &c.; *Thecosmilia Martini*, De From.; *Isastræa Murchisonæ*, Wr.; Plant-remains, wood, &c.	Applecross; Hallaig, Raasay; Lussay and other parts of Strath in Skye; Surdil and Mingary in Ardnamurchan; Ru-na-Gal, I. of Mull; Craignure, I. of Mull; South coast of Mull (?).	Zone of *Ammonites angulatus* and *A. planorbis*.
POIKILITIC.	Soft reddish argillaceous and sandy beds, with some hard sandstones and conglomerates, occasional bands of concretionary siliceous limestones ("cornstone") and gypsum.	200+	Casts of shells (*Cyrena*?).	Greenstone Point, Gruinard Bay; Ru-na-Leac, I. of Raasay; Strath; Skye; Surdil and Sron More, Ardnamurchan; Innimore of Ardtornish; Morvern.	Trias and (Permian?).
	Red and variegated clays and marls, with occasional bands of cornstone &c.	200+	No fossils found.	Greenstone Point &c.; Ru-na-Leac, I. of Raasay; Innimore of Ardtornish; Ardtornish Towers and shore of Loch Aline.	
	Coarse breccias and conglomerates alternating with sandstones, the rocks often having much calcareous material in their matrix.	500+	No fossils found.	Greenstone Point; Point of Ayre, I. of Raasay; Strath; Skye; Ru-Geur, Skye; Surdil and Sron More, Ardnamurchan; Innimore of Ardtornish; Craignure, I. of Mull.	

CARBONIFEROUS AND OTHER PALÆOZOIC ROCKS.

hereafter be proved to belong to the period between the Cretaceous and the Eocene, to the latter formation itself, or even to the Miocene.

With regard to the underlying beds no such doubt, fortunately, exists. We have clearly marine representatives of the Chalk with *Belemnitella mucronata*, Schloth., and of the Cenomanian or Upper Greensand; and the variable estuarine strata between these two marine series must be referred to the whole or to some part of the period represented in other areas by the Lower or Middle Chalk.

The existence of strata of littoral and estuarine origin, intercalated in the Upper-Cretaceous series in Bohemia and other parts of Eastern Europe, is a well-known fact. On the other hand, the recent researches carried on with so much perseverance by the United-States geologists in the western district of the North-American continent have rendered us familiar with thick formations of freshwater and terrestrial strata representing the same Upper-Cretaceous period, and also the interval between it and the Tertiary. Under these circumstances the discovery of these Scottish littoral and estuarine deposits is of very great interest—enabling us, as it does, to define a portion of the northern limits of the Cretaceous ocean. The bearing of these facts will be more fully discussed in the fourth and concluding part of this memoir.

VI. Conclusion.

Although, as I have before stated, it has been thought advisable to postpone the discussion of the numerous problems of interest which suggest themselves to the student of the remarkable relics of the Secondary rocks in the Scottish Highlands, until the fourth and concluding portion of this memoir is published—yet there are several questions which at the present time engage the minds of geologists upon which, as it appears to me, the facts and arguments of the present part of this memoir have an important bearing; and these it may not be undesirable to notice briefly at the present stage of the inquiry. Other and more general discussions will be allowed to stand over till such time as I have made the proposed comparison between the characters and modes of preservation of the beds under consideration and those of their equivalents in Ireland, England, Scandinavia, and other portions of the Continent.

I may briefly point out in the first place the great interest which attaches to the fact that there exists in the north-western part of the British archipelago a series of strata of Cretaceous age exhibiting evidence of the prevalence of estuarine alternating with marine conditions. The great and deserved amount of attention which is now directed to the similar beds, developed on such a grand scale in Western America, renders the discovery of the minute Scottish representatives of the period particularly important at the present time. It is tantalizing, however, to the British geologist to have to confess that, while he can demonstrate the undoubted fact of the existence of such strata, yet he is obliged to abandon almost all hope of ever being able to collect from them (such is the imperfect manner of their exposure) the interesting remains of plant- and animal-life which would be so invaluable to him in enabling him to trace the ancestry of some of the Tertiary and recent types of life. The discussion of the question concerning the probable existence of land during the Cretaceous and later periods in the area now occupied by the Atlantic, and the more general problem of the possible permanence of the position of the great continents during vast periods of geological time, we reserve for a future occasion.

It is impossible to avoid noticing, in passing, the singular fact that in the north-western part of our archipelago both the Lower-Silurian and Upper-Cretaceous strata lose their ordinary characters, and show curious points of similarity to those displayed by the beds of equivalent age in the North-American continent.

The suggestion made some time ago, that the present Atlantic bed was in some sense "continuous with" the ancient Chalk strata of England, has been so thoroughly disposed of on palæontological and other grounds already, that it is perhaps scarcely necessary even to allude to it here. But if any trace of vitality still lingers in such a theory—and it is the nature of error to produce perennial crops—it is surely only necessary to point to the interesting fact, that in tracing the Chalk strata towards the Atlantic area they are found to assume estuarine characters and to afford the most unmistakable evidence of the close proximity of land in that direction, in order to set the question permanently at rest.

The conviction, however, that makes itself most strongly felt from a consideration of the details and arguments of the present part of this memoir, is that of the extreme danger to the geological inquirer of giving any important weight in his reasoning to *negative* evidence. The conclusions of the present paper, which will be strengthened in various ways by those which I hope to discuss on a future occasion, lend the strongest grounds of support to the view that over the greatest part of the British Islands, and far beyond that area, strata of various ages, from the Carboniferous to the Chalk inclusive, were once very widely spread, and have been removed by denudation during and since Mesozoic times. As a corollary from this proposition, which I believe that it will be possible to establish by the most unassailable arguments, we can scarcely help inferring that the reasonings so frequently indulged in concerning the former limits of areas of deposition in the past are of a very unsafe character, depending as they do in so many instances on such purely negative evidence as the absence of strata of a particular age from certain districts. We are too apt, perhaps, to forget how enormous has been the work of destruction of older strata in past times by denudation; and interesting as the new and isolated deposits of Carboniferous, Poikilitic, and Cretaceous strata (which I have now described for the first time as occurring in the Highlands of Scotland) are in themselves, yet their value and importance to the student of geology will be greatly enhanced if they be allowed to serve—as I believe they ought to do—as monuments of the enormous destruction effected by denuding agencies during past geological epochs, and standing protests against the danger in geological speculations of drawing deductions from negative evidence. In palæontological geology the warning is perhaps scarcely necessary; for an accidental discovery of fossils has again and again occurred to produce a deep, timely, and salutary impression on the minds of rash theorists; and it is not perhaps too much to hope that an equal service will be rendered to the cultivators of physical geology by the discovery of these isolated and strangely preserved relics of vast formations in the Scottish Highlands.

NOTE *on the* FORAMINIFERA *and other* ORGANISMS *in the* CHALK *of the* HEBRIDES. By Professor T. RUPERT JONES, F.R.S., F.G.S.

[In the examination of specimens of the Cretaceous Rocks of the Hebrides I have been aided by Professors W. Kitchen Parker and T. Rupert Jones; and the latter has drawn up the following note on the sections which I submitted to him—J. W. J.]

No. O, 2. "Siliceous Chalk, Carsaig, W., Isle of Mull," and No. O. 3. "Siliceous Chalk, Beinn-y-Hattan," are specimens of *Inoceramus*-chalk—that is, made up to a great extent of prisms of *Inoceramus*-shell. In No. 3 some of these are *pyritized*. Foraminifera are abundantly present, constituting the matrix in which the prisms are imbedded. *Globigerina cretacea* is the most abundant; and others are present, such as *Dentalina*, *Virgulina*, *Bulimina*, *Planorbulina*.

No. O, 3*. "Siliceous 'Chalk,' Carsaig, E., Isle of Mull," and No. O, 4. "Flinty Chalk, Beinn-y-Hattan," are specimens of silicified *Globigerina*-chalk. The Foraminifera are much obscured, except here and there; and *Globigerina cretacea* is the only Foraminifer easily distinguished. *Inoceramus*-prisms and Sponge-spicules are obscurely indicated. Sand-grains (quartz) are present.

The occurrence of *Inoceramus*-prisms as important constituents of some kinds of Chalk has long been known. They form a large proportion of some strata of the Chalk at Charlton, near Woolwich, and elsewhere along the *Inoceramus*-zones.

Such prisms are figured by Prof. W. C. Williamson in his memoir "On some of the Microscopical Objects found in the mud of the Levant," &c. 1847, 'Manchester Lit. & Phil. Soc. Memoirs,' vol. viii. These prisms, figured in pl. iv. figs. 85 and 86, are described as such, and as being abundant in the "Chalk-detritus" (rotten Chalk-marl) of Charing, Kent, at pages 80, 81.

Prisms of *Inoceramus* are carefully described and figured in H. Eley's 'Geology in the Garden,' 8vo. 1859, p. 177, pl. i. fig. 1, &c., as abundant in some English Chalk-flints; and some are apparent in fig. 113, p. 210, of Heer's 'Primæval World of Switzerland,' 1876, illustrating a microscopic section of the glauconitic shales of the Swiss Gault with *Inoceramus concentricus*.

No. O, 4. Siliceous "Chalk, Gribun, Isle of Mull," is probably a *Globigerina*-chalk; but the Foraminifera are only obscurely indicated; so also are Sponge-spicules and *Inoceramus*-prisms.

No. O, 5. "Siliceous Chalk, Beinn-y-Hattan," is a *Globigerina*-chalk, composed of *Globigerina cretacea*, with *Textularia* and *Planorbulina*, and probably smaller organisms, Coccoliths, &c. Compare the hard Chalk from Larne (Antrim), which is very similar. Compare also the woodcuts, figs. 104–113, pp. 203–210, in the English edition of Heer's 'Primæval World of Switzerland,' 1876, for similar rock-material and organisms. These are more specially treated of in the 'Transact. Roy. Geol. Society of Ireland,' November 1872, where the Foraminiferal Limestone of Antrim is described.

No. O, 6. "Calcareous Grit, U.G., Carsaig, Mull." This siliceous and glauconitic grit, with calcareous cement, contains some pieces of (Molluscan?) shell and Foraminifera, such as *Textularia* and *Planorbulina*.

No. O, 8. "Micaceous glauconitic Sandstone, U. G. Loch Aline." This contains some obscure Sponge-spicules. Foraminifera, it is well known, are very abundant in the Chalk, constituting a very large proportion of its material. Mr. H. C. Sorby has estimated that in some specimens of chalk the shells and fragments of *Globigerinæ* form nearly 90 per cent. of the bulk. Coccoliths and Rhabdoliths, still smaller calcareous organisms, form the finer material of the Chalk. The small Entomostracan valves are sometimes in abundance; and prisms of *Inoceramus*-shells make up a large proportion of the Chalk in some places. Polycystina have not been noticed in the British Chalk. A very few Diatomaceæ were recorded by Ehrenberg from the Gravesend Chalk, but have not been otherwise observed. Foraminifers and Coccoliths are always present. The former belong to such kinds as at present live in the sea, from the littoral zone down to depths of 100 fathoms or more. Some of the same kinds, however, exist now at great oceanic depths; but the abyssal *Globigerinæ* of the present ocean grow much larger and coarser than those found in the Chalk.

The prepared specimens under notice from Carsaig, Beinn-y-Hattan, and Gribun fully illustrate the theory of the pseudomorphosis of the calcareous mud, or chalk-ooze, into silex, as established by Bischoff, and adopted by Duncan, Dowker, and others. See 'Proceed. Geol. Assoc.' vol. iv. 1876, p. 451, &c.

EXPLANATION OF PLATE XXXI.

In Fig. 1 an attempt has been made to show the general relations of the Volcanic rocks of the Western Isles, in illustration of the second portion of this memoir, which was specially devoted to the consideration of the ancient volcanoes of the district, both those of Newer Palæozoic and those of Tertiary age. In conformity with the plan adopted in the more detailed map of Mull, published with the second part of the memoir. the acid volcanic rocks of Tertiary age have been indicated by tints of red, the basic volcanic rocks of the same period by shades of blue, the darker colour in each case representing the intrusive masses, the paler the lavas, and the dotted surfaces tuffs and agglomerates. The fragments which have escaped denudation, of the great volcanoes of Mull, Ardnamurchan, Mull, and Skye respectively, can readily be seen from an inspection of this map, that of St. Kilda lying outside its limits. The little group of the Shiant Isles probably represents the only remaining vestige of another great volcanic centre, which has been almost wholly removed by the denuding forces.

The same map is made to illustrate the distribution of those isolated patches of Secondary strata with which the present part of the memoir more particularly deals. As these exposures are not only of minute size, often, indeed, even when comprising series of beds hundreds or thousands of feet in thickness, covering no superficial area, but being displayed in absolutely vertical precipices under the almost everywhere superincumbent Tertiary volcanic rocks, the ordinary mode of representing strata of different ages on geological maps wholly fails us here. I have therefore coloured all the beds intervening between the Palæozoic and the Tertiary of one uniform conspicuous tint, and endeavoured by means of the lettering to show the ages of the various strata seen at different points. In order that they might be visible at all on a map of this small scale, however, the areas covered by the Secondary strata have had to be exaggerated in most cases.

Fig. 2 illustrates in a somewhat diagrammatic way the relations of the Secondary rocks to those older and younger than them respectively, especially the preservation of outlying patches of the Secondary strata, and the effects produced by the great post-Miocene fault of the Innimore of Ardtornish.

Discussion.

Prof. Ramsay remarked that the material placed before the Meeting was so vast in amount and so condensed in form, that it was impossible to grapple with all the author's statements. In general he had nothing to object to what the author had said; and probably if all the data had been laid before the Meeting, every one would agree to the statements contained in the paper. But, no doubt for want of time, the author had, it seemed to him, left some matters a little obscure. Did he mean to imply that the whole area of Scotland had once been overlain by Carboniferous strata? Prof. Ramsay quite agreed that a large portion of the British Islands was once so covered—three fourths of Ireland and a great part of England—but, he thought, not all Wales, nor all the Highlands of Scotland. His reasons were drawn from the history of the Palæozoic rocks. In the case of the Old Red Sandstone of Scotland, Mr. Godwin-Austen had proved this to have been deposited in freshwater lakes. The masses of Old Red conglomerate in Scotland were sometimes of glacial origin, and were composed of the detritus of older Highland Silurian rocks. There must then have been lofty mountains for the origination of such glaciers; and there was high land during the Old-Red-Sandstone period. After the Old Red Sandstone we find great flat territories, thin beds of limestone, and of coal with underclays which partly showed estuarine conditions, and there must have been dry land in the neighbourhood. Evidence is still wanting to prove that the whole of the Highlands were covered by coal-beds. With regard to the faults described by the author, Prof. Ramsay thought such enormous downthrows as some of those mentioned to be improbable. He would remind his hearers that a fault may have great magnitude in one part, and die out to nothing within a distance of a few miles. All the mountains of Scotland were certainly not covered by Oolitic and Liassic strata.

With regard to the origin of the New Red Sandstone, he would ask whether the existing beds of rock-salt were consistent with deep-sea formation.

Prof. Hughes could not follow the author altogether in his conclusions as to the age of the present surface of the district described. If the question was whether any part of the surface is now approximately the same as it was before the Pliocene period, he thought that much might be learned from a consideration of the plains of marine denudation which can be traced from districts in the south, where there is some evidence as to their age; and it would appear that some of these are Precretaceous, the margin of a lower plain being a shore-line along hills, the tops of which form part of a higher and probably older plain. He thought the greater part of the sculpturing should be referred to the period before the Pliocene.

Mr. Carruthers stated that he had examined the exceedingly interesting vegetable remains brought by Prof. Judd, and that their nature left no doubt as to their truly belonging to the Coal-measures. They belong to the Upper and Middle series. To him this result had come quite unexpectedly. Could we also have fossils from the later estuarine rocks, much light might be thrown upon them. The Cretaceous fossils have Eocene affinities.

Mr. Whitaker remarked that the Upper Estuarine beds were described as being clays and sands, and inquired what evidence there was of their being Cretaceous. May not some of them be Tertiary? The description of them is equally applicable to Tertiary and to Cretaceous deposits. He further inquired whether the lavas correspond with those on the north-east coasts of Ireland, and how they lie on the beds under them, and to how great an extent were the latter altered. How far do these Cretaceous beds answer to those at Aix-la-Chapelle?

Mr. Woodward said that he saw M. Devey's collection at Aix-la-Chapelle in April last, and that it contained many plants of Pliocene age. He thought that the leaves in the specimens on the table had a remarkably Eocene facies, and in this respect resembled those found in America. He inquired whether Prof. Judd had observed the lignite-beds in Antrim.

Dr. Hicks stated that in the district particularly studied by him he had found that great faults were very persistent through any distances.

Rev. J. F. Blake referred to the difference in character of the rocks described from those of England. The Carboniferous beds were formed in shallow water, near which there must have been high land; and this would have prevented the continuity of the several deposits. The estuarine character was repeated in the Oolitic series in Yorkshire, as also in the Lias. These deposits overspread large areas, but were not continuous, and could not have been formed in deep seas. So, too, with regard to the Chalk and Upper Greensand. He inquired whether Chalk is a shallow- or a deep-sea formation. He had always thought it was the latter; but Dr. Gwyn Jeffreys had

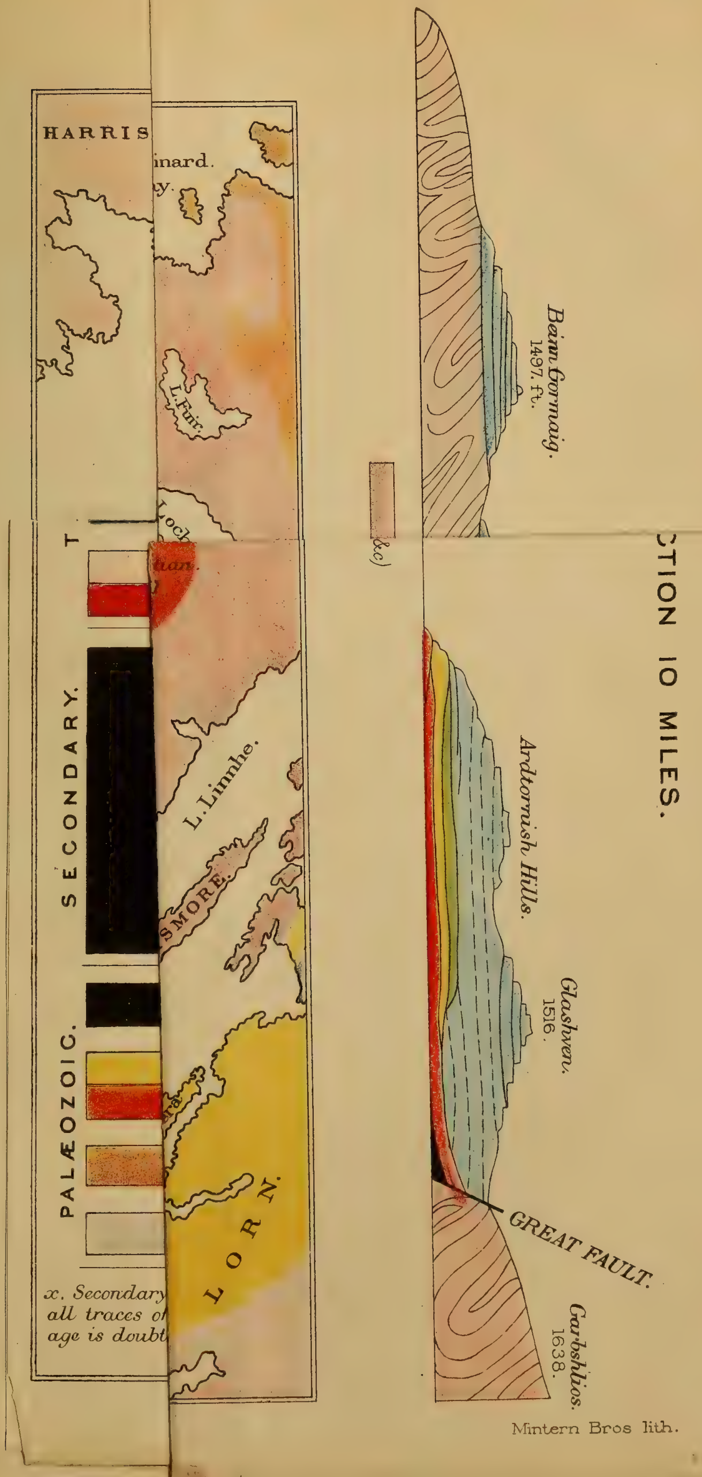

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Fig. 1. MAP OF THE INNER HEBRIDES, TO ILLUSTRATE THE DISTRIBUTION OF THE SECONDARY STRATA, AND THE TERTIARY VOLCANIC ROCKS.

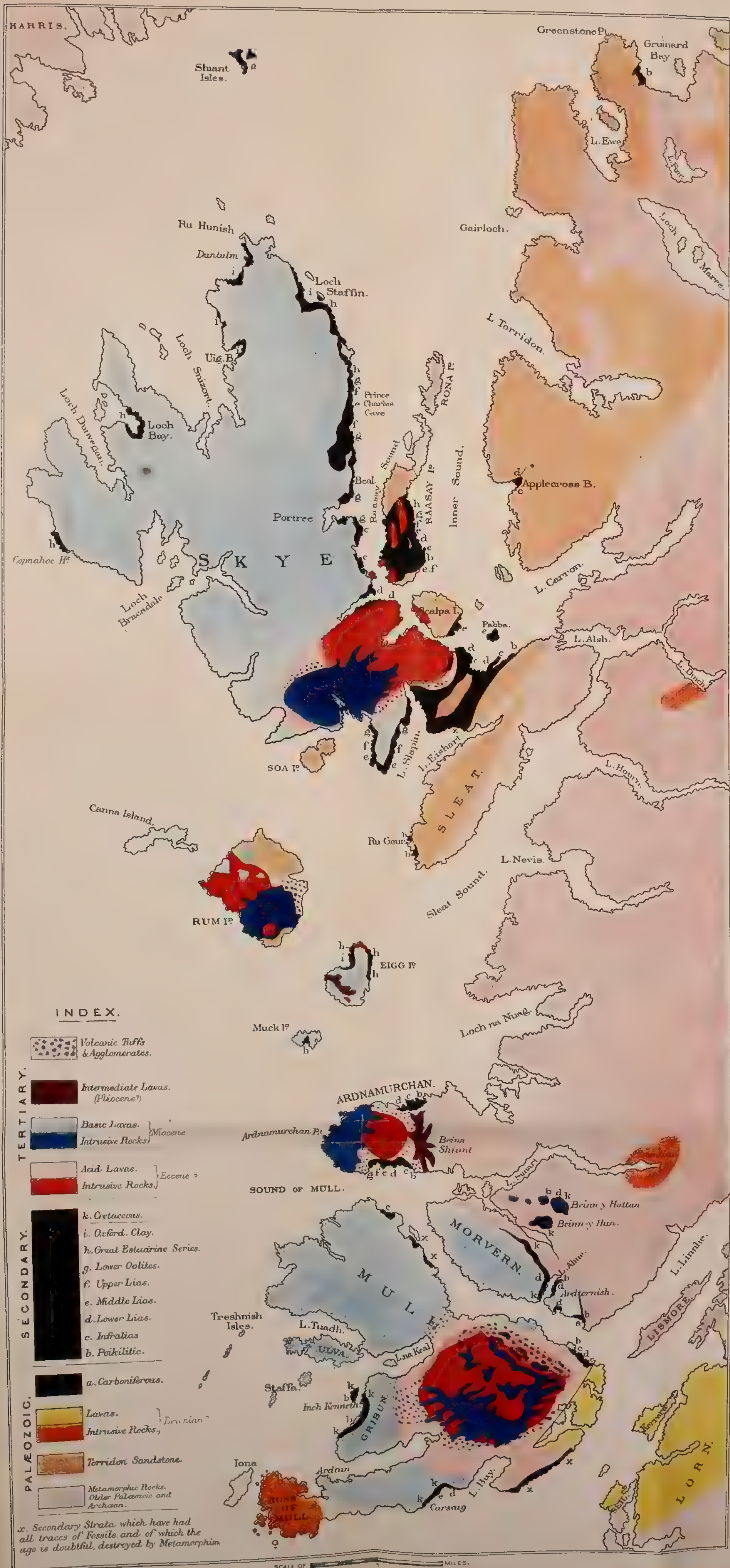
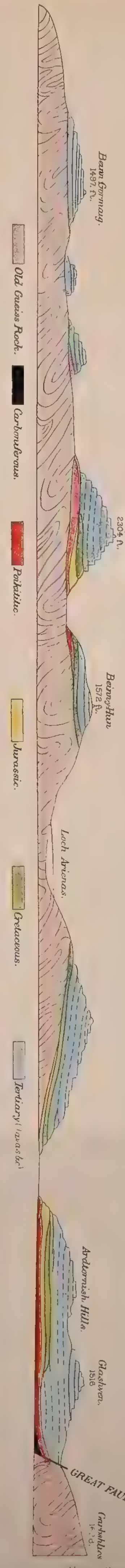


Fig. 2. GENERALIZED SECTION ACROSS THE DISTRICT OF MORVERN-ARGYLLSHIRE. LENGTH OF THE SECTION 10 MILES.



Mintern Bros. lith.

lately declared its fossils to be those of a comparatively shallow sea. He also asked whether the Chalk in the district described was like that of the north of Ireland.

Mr. Sollas remarked that the outlines of land and sea were of first-rate interest to the geologist; and inquired whether a broad gulf of waters stretching across the Triassic plains of Cheshire and Lancashire, and over the North-east of Ireland and the North-west of Scotland, would not account for the facts without assuming a very general submergence of the British Isles. It seemed to him that to say from the present absence of Oolitic beds over large areas that such beds had never been was more philosophical than to deduce from it their former existence. In support of his opinions he indicated that in the south-west the Carboniferous land had a fringe of New Red Sandstone, and the Lower Lias had no Oolite over it. In the South-west there was evidence of shallow water close to a coast-line. It seemed to him that the absence of sedimentary beds proved that there had been no submergence. With regard to the Jurassic period, his notion was that all Wales, Devonshire, Cornwall, and the Pennine chain have been above water since the time of the Lower Lias.

The Author, in reply, said that Prof. Ramsay and Prof. Hughes seemed to think he ought to have approached his subject from their standpoint rather than from his own. All will agree that the Lias and the Chalk were not formed in lakes. Fragments of lavas occur throughout large areas; and under all of these the Secondary rocks are preserved. If they were not originally continuous across the existing gaps, we must assume that the sea went exactly to these limited spots, which was so unlikely as to be almost absurd. In reply to Mr. Whitaker, he said that the evidence was in favour of the Cretaceous nature of the beds, but the proof that they were not Eocene was not absolute. The basaltic lavas were Miocene, the others Eocene. The relations of lavas to the beds beneath them had been dealt with in a former paper. To Mr. Woodward he said that the Antrim lignites are not Cretaceous, but Tertiary; to Mr. Blake, that all the beds are not estuarine, but there are immense thicknesses of marine deposits with fossils; and to Mr. Sollas, that he preferred at present dealing with the ascertained facts, reserving the treatment of the theoretical questions involved for a future paper.

40. Note *on an* Os articulare, *presumably that of* Iguanodon Mantelli. By J. W. Hulke, Esq., F.R.S., F.G.S. (Read March 20, 1878.)

More than forty years have passed since the late indefatigable Gideon Mantell's discovery of a tooth first brought to light the former existence of the Iguanodon. Since then the remains of this great Dinosaur have been plentifully obtained from the Wealden districts in Kent, Sussex, and the Isle of Wight; and of most segments of its skeleton we now possess a better knowledge than we have of the bony frame of any of its larger contemporaries.

It is of the heads of these Dinosaurs that our knowledge continues to this day very defective. Tooth-bearing portions of the mandibles and maxillæ of *Iguanodon Mantelli* are now to be seen in the principal public and in some private collections; but of crania proper which can with much probability be referred to *Iguanodon*, the only remains known to me are a mutilated base, with side-walls, and several fragments of the vault and sides of the skull in the Rev. W. Fox's collection, obtained near Brixton, Isle of Wight, and the skull which, several years ago, I brought under the notice of this Society, and of which a figure is given in vol. xxvii. pl. xi. of the Quarterly Journal. It came from the Wealden clay at Brooke.

The articular element of the mandible is one of the missing parts which has escaped recognition (no mandible yet figured, or, so far as I know, in any collection, possesses it); and I am happy to have now an opportunity, through the courtesy of Mr. Fox, of bringing before the Society a form of articular bone to which, from intrinsic characters, and also from its *gisement*, the Iguanodon appears to me to have a paramount claim.

After several years of fruitless search in every accessible collection for the Iguanodon's *os articulare*, Mr. Fox, in 1869, submitted to me a bone the skeletal place of which he had not been able to decide; and indeed, apart from the rest of the mandible, its identification by one who had not specially studied anatomy offered considerable difficulty. There could not, however, be any doubt that the bone in question was the detached *os articulare* of a very large reptilian mandible. Mr. Fox had long possessed three, which, as he afterwards told me, he had obtained from the same localities that had yielded him magnificent mandibular rami of Mantell's Iguanodon. I suggested at the time to their fortunate possessor that he should publish an account of these valuable specimens; but it appeared to him wiser to wait for additional evidence confirmatory of their really belonging to the Iguanodon. Since then he has obtained two others, making five in all, of which four belong to right rami; and in May of last year he proposed to me to communicate to the Society an account of them.

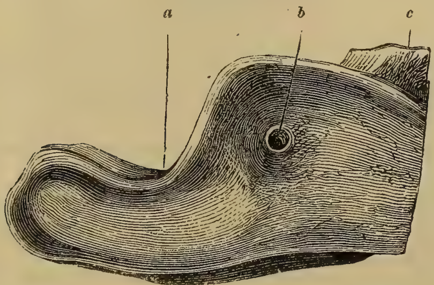
Taking the least imperfect specimen as the type (in all the anterior border is mutilated), this os articulare may be described as consisting of a vertical plate largely appearing in the outer surface of the jaw, and of a horizontal plate projecting inwards from the former in a shelf-like manner, bearing the tympanic articular surface.

Vertical plate.—The outer surface of this is smooth; so much of it as lies in advance of the tympanic joint has a roughly quadrilateral outline (see fig. 1); and here its vertical depth is about double that of the part behind it abreast of the tympanic joint, which narrows chiefly by the sharp descent of the upper border of the plate. Below, the quadrilateral part is bent inwards, which makes its upper border overhang, particularly above a large foramen to be shortly described. Abreast of the tympanic joint the surface of the plate bends inwards, through the tapering-off of the hinder end of the jaw.

At the bottom of a shallow circular pit, rather behind and above the middle of the quadrilateral part of this plate, is a large foramen, which would give passage to a cedar drawing-pencil (fig. 1, *b*). Its inner opening is deeply placed beneath and hidden by a thin lip or sheet rising from the front of the tympanic surface (figs. 1, 2, 3, *c*).

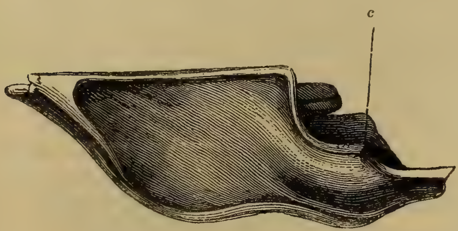
Figs. 1–4.—*Right Os articulare of* Iguanodon, *one third natural size.*

Fig. 1.—*Outer View.*



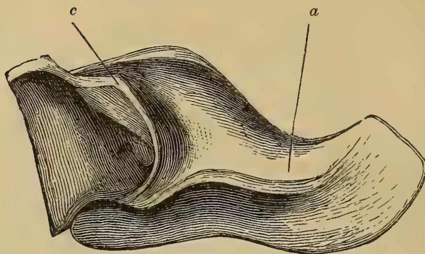
a. Tympanic joint. *b.* Foramen. *c.* Ascending process from tympanic surface.

Fig. 2.—*Tympanic Surface, from above.*



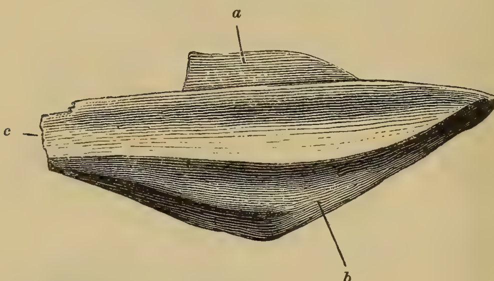
c. Ascending process.

Fig. 3.—*Inner View.*



a. Tympanic surface. *c.* Ascending process.

Fig. 4.—*Under Surface.*



a. Under surface of articular face. *b.* Outer surface.
c. Sutural surface for angular bone.

This foramen is present in all Mr. Fox's specimens, and may be looked on as constant in this type of articular bone. I find it also in the *Hypsilophodon's* mandible. A perforation in a bony element, and not a space between the angular, surangular, and dentary pieces, this foramen does not correspond to the large oval opening in the mandible of extant and extinct crocodilians, but rather to the foramen, sometimes double, present in the surangular element in some extant lizards. (Such foramina are to be seen in *Iguana tuberculata*, 672 A, and *Sphenodon*, 662 *a*, Mus. Roy. Coll. Surg.)

In its whole preserved extent the upper border of the vertical plate is a thin, non-articular, smooth, rounded lip. From in front it gradually and gently rises to a short distance behind the large foramen just described, where it reaches its greatest height; and thence it descends in a sinuous S-curve, the first bend of which is steep and abrupt, the second bend shallow and open. In front of the tympanic joint the whole inner surface of the vertical plate is non-articular, but less smooth than the outer surface of the same part. It is much hidden by the sheet rising from the front of the tympanic surface, with which it forms the sides of a large and deep hollow, in the fresh state presumably filled with the persistent remains of the cartilaginous rod upon which the bony elements of the jaw were laid down. All that part of the vertical plate which underlies and supports the tympanic surface is stout and sutural. The lower border of the vertical plate in front, where it is broken through, is 1 to $1\frac{1}{8}$ inch wide; and behind it tapers to nothing at the hinder end of the jaw. In its whole length this border is longitudinally grooved by sutural marks.

The horizontal plate bearing the tympanic surface, viewed from above, has a roughly triangular outline (fig. 2; fig. 3 *a*). Its inner border is almost straight; and for its anterior two thirds it projects inwards beyond the vertical plate in a shelf-like manner. It meets in front the anterior border, making with this an angle which, in a less incomplete example, ran forward for about an inch in a tongue-like form. The anterior border, rising and at the same time acquiring a slight outward twist, becomes a highly inclined curved sheet, which above, at its outer border, is separated by a shallow groove from the upper lip of the vertical plate.

The tympanic articular surface is hollow from side to side, and also from before backward. Its greatest length is in the direction of the axis of the jaw; and in this direction, behind, a low median rising imperfectly marks off an inner and an outer part.

The above details will have made it apparent that the mandible represented by this articular bone differed greatly from that of Crocodilia, and in a less degree from those of extant lizards; whilst in some important features it resembled that of *Hypsilophodon Foxii*. This, and the occurrence of the bone in relative abundance in the same beds and localities which have yielded Iguanodon-mandibles, always wanting the articular element, appear to me sufficient warrant for (at least provisionally) referring this os articulare to the Iguanodon.

41. *On the* Affinities *of the* Mosasauridæ, *Gervais, as exemplified in the* Bony Structure *of the* Fore Fin. By Prof. Owen, C.B. F.R.S., F.G.S., &c.

In the year 1848 Professor Henry Rogers submitted to me a series of fossil remains which he had discovered in a Greensand deposit in New Jersey, United States. The results of my examination were communicated to the Geological Society, January 31, 1849*. The paper was sent, in due course, to Referees for a 'Report,' but was lost.

Fortunately the President, Sir H. T. De La Beche, had made notes of the chief conclusions communicated and discussed on the 31st of January, and referred to them in his "Anniversary Address" delivered February 16, 1849†. To these brief notices I added, at the request of the Council, some observations on the characters of the skull and vertebræ deduced from the fossils, which I referred to the genus *Mosasaurus*; and, in reference to the metacarpal or metatarsal and phalangeal bones of the same genus, I quoted the President's note, "that they indicated the extremities of the great Saurian to have been organized according to the type of the existing *Lacertilia*, and not of the *Enaliosauria*, or marine lizards"‡.

Of the natatory character of the limb to which these metacarpal and phalangeal bones belonged, there was no question. The question was, to what type of natatory extremity that of the *Mosasaurus* should be referred? Cuvier had recorded his conclusion that the fins of the Mosasaur were more or less like those of the *Delphinidæ* or of the *Plesiosauri* §.

Subsequently, in my 'Monograph on the Fossil Reptiles of the Cretaceous Formations' ||, referring the genus *Mosasaurus* to a tribe *Natantia* (p. 29), of the order *Lacertilia* (p. 19), I stated with regard to the phalangeal bones, that "they indicate the extremities of that gigantic Lizard to have been organized according to the type of the existing *Lacertilia*, and not of the *Enaliosauria* or *Cetacea*" (p. 40).

The value of such conclusion from the few materials then at my command could only be estimated by comparison with a more complete specimen of a Mosasaurian fin; and such has been obtained by the able and indefatigable palæontologist, Prof. O. C. Marsh, who has given a description and figure of the specimen in his memoir "On the Structure of the Skull and Limbs in Mosasauroid Reptiles," in the 'American Journal of Science and Arts,' vol. iii. June 1872.

* Quarterly Journal of the Geological Society of London, vol. v. p. 380.

† *Ib.* p. xliii. ‡ *Ib.* p. 382.

§ "Les os des mains et des pieds, autant qu'on les connoît, sembleroient au contraire avoir appartenu à des espèces de nageoires assez contractées, et plus ou moins semblables à celles des dauphins ou des plésiosaurus."—*Ossem. Foss.* 4to, 1829, t. v. 2de partie, p. 336.

|| Part I., in Volume of the Palæontographical Society, issued in 1851.

Fig. 1.—*Bones of the Fore Limb of a Cetacean.*

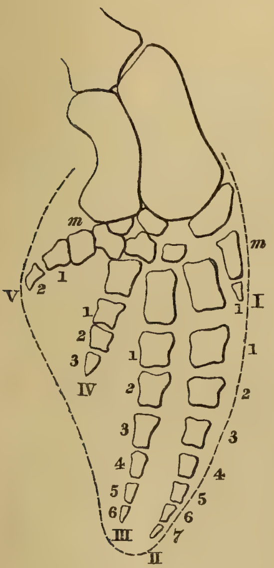


Fig. 3.—*Bones of the Fore Limb of a Lacertian.*

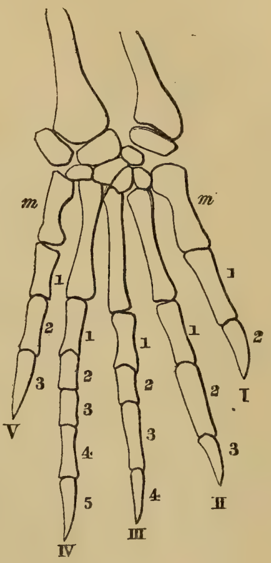


Fig. 2.—*Bones of the Fore Limb of a Plesiosaur.*

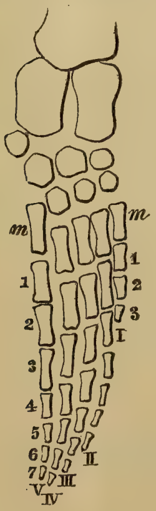
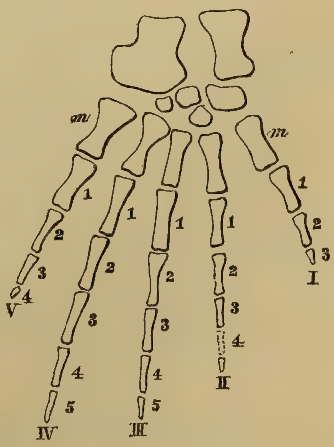


Fig. 4.—*Bones of the Fore Limb of a Mosasaur.*



m. Metacarpals. I–V. The digits. 1, 2, 3, 4, &c. Phalanges.

I subjoin (p. 749, fig. 4) a copy (reduced one half) of his reconstruction* of the skeleton of the fore limb of the species of Mosasauroid which he calls *Lestosaurus simus,* which figure may be taken to be sufficiently accurate to serve as a subject of comparison with the bones of the fore limb of a Cetacean (*ib.* fig. 1), of a Plesiosaur (*ib.* fig. 2), and of a Lacertian (*ib.* fig. 3).

Prof. Marsh writes :—"This specimen clearly establishes the fact, hitherto unknown, that the number of digits in the manus was five, and that the longest digits had six phalanges, and the shortest had but four. Moreover, that the paddle was expanded as in some of the Cetaceans, and not contracted as in *Ichthyosaurus, Plesiosaurus*, and other Enaliosaurs" (*op. cit.* p. 4).

The author thus inclines to the Cetacean alternative of Cuvier's view, whilst rejecting, with me, the Enaliosaurian one. As to any approach to the Lacertian type in the framework of the fore limb of his Mosasauroid Prof. Marsh is silent; but he rightly recognizes such approach in the structure of the coracoid element of the supporting arch of that fin.

In his enumeration of the phalanges Prof. Marsh reckons the metacarpal as one; in my copy of his figure (p. 749, fig. 4), I connote these bones as in my figure of the Lacertian fore limb (fig. 3), homologizing the proximal row, in both limbs, as metacarpals.

The first character to be noted in that limb of the Cetacean (*ib.* fig. 1) is the sudden acquisition of length by the digit II and the more or less gradual shortening of the digits III, IV, and V,—the first digit, moreover, being chiefly represented by its short metacarpal bone, to which may be added, in some species, two small phalanges (e. g. *Phocæna communis, Globiocephalus propinquus, Balæna australis, Pontoporia tenuirostris*), while *Microptera bidens, Ziphius cavirostris*, and some other Cetacea have but one small pointed phalanx added to the short metacarpal †: but no known Cetacean deviates materially in reference to the present comparison from the type figured (fig. 1). The digits increase in length from the ulnar to the radial side of the fin, as far as the second digit.

In *Plesiosaurus* the metacarpal of the pollex (I) may support three phalanges; the second digit (II), as in Cetacea, acquires a sudden increase in length and number of phalanges, amounting to five or six ; the third (III) and fourth (IV) digits slightly increase in length, each having six phalanges; and the fifth digit (V) has seven phalanges, although, from the less advanced position of the metacarpal bone, it seems not longer than the fourth digit. But the general type is exemplified by an increase in length of the digits from the radial to the ulnar side of the fin. The metacarpal must be added in reference to the number of phalanges assigned to *Mosasaurus* by Prof. Marsh.

* Plate X. *op. cit.* (½ nat. size).

† A. W. Malm, Kongl. Svenska Vetenskaps-Akademiens Handlingar. Bandet 9, No. 2, tafl. IV., V.

In the Lizard (*Monitor niloticus*, fig. 3), the first digit (I) is the shortest; the second (II) shows a marked increase of length; this slightly augments in the third (III) and again in the fourth digit (IV), while the fifth (V) becomes shortened, though not in the same degree as the first.

The general proportions of the five digits show a near equality of the three middle ones (II, III, IV), which are the longest, and a marked inferiority in the length of the first and fifth digits. The increase in length is from the radial to the ulnar side, as far as the fourth digit; then stops more decidedly, the fifth digit being much shorter, although the metacarpal is on the same level as the rest.

Now this is the general character also of the digits of the fore fin in the Mosasaurian, fig. 4. The three middle digits are subequal, slightly gaining in length from the second (II) to the fourth (IV); while the first (I) and fifth (V) are much shorter; and of these the first is shorter than the fifth. The numerical formula of the phalanges in the *Monitor* and majority of Lizards is 2, 3, 4, 5, 3; in the Mosasauroid, as restored by Prof. Marsh, the formula appears to be 3, 5, 5, 5, 4. But it must be remembered "that a few of the distal phalanges were somewhat displaced;" and a phalanx is added, in dotted outline, to digit II in plate x. of the 'Memoir.' It may be allowable to conjecture, if the bones of the fore fin of a Mosasauroid should be discovered without the degree of displacement of phalanges to which Prof. Marsh's specimen had been subjected, that a nearer approach to the Lacertian formula may be demonstrated than is shown in p. 749, fig. 4.

This, however, is by no means required to form a judgment on the main issue from the bones of the fore fin as restored by Prof. Marsh, viz. that the type of such fin is Lacertian rather than Plesiosaurian or Cetacean. The differences in the latter types are too great to need further remark.

I may here, however, refer to a statement by Prof. Cope, bearing upon another element in relation to the affinity of *Mosasaurus*, viz. that the figure 23, p. 709, of my paper "On the Rank and Affinities in the Reptilian Class of the *Mosasauridæ*"* is copied from "a figure of a vertebra of *Clidastes stenops*, from which the zygosphene has been accidentally broken away"†.

It will be seen, in referring to plate xviii. of Cope's great work on 'The Vertebrata of the Cretaceous Formations,' 4to, 1875, that, in selecting fig. 4 *a* to illustrate my comparison with the vertebræ of *Python*, fig. 24, and *Iguana*, fig. 22 of my paper, I took the least mutilated of the figures in Prof. Cope's plate, and one that gave no indication on the side figured of any fracture or loss of parts. My copy is exact, and the fault is with Prof. Cope's artist. The Professor refers to several other figures, all of more or less mutilated

* Quart. Journ. Geol. Soc., November 1877.

† 'Bulletin of the United-States Geological Survey,' vol. iv. no. 1, p. 300, February 1878.

vertebræ, in which he states that I "will find the zygosphene distinctly represented" *. If that part had been indicated by any letter or mark, I should gladly have recognized it; for the alleged structure is an interesting addition to the osteology of the Mosasauroids.

Accepting the testimony of these figures, according to the author's determination of the parts of the fractured vertebræ, the Mosasaurian skeleton offers, in the genus *Clidastes*, another ground of comparison with the Ophidian, on the one hand, and the Lacertian on the other. Certain members of the latter order, forming the family of the Iguanidæ, show, in the trunk-vertebræ, the same super-additions which characterize those of the Ophidia. But there are modifications of the zygosphene and zygantrum which, with minor differences, distinguish the Iguanian from the Ophidian vertebræ.

I venture to repeat, therefore, the suggestion in the paper above cited, p. 709, of a desire to possess an entire vertebra, or a cast of such, of a Mosasaurian showing the zygosphene and zygantrum, in order to compare it with an Ophidian vertebra (fig. 24, p. 709, Quart. Journ. Geol. Soc., Nov. 1877) and an Iguanian vertebra (fig. 22, *loc. cit.*).

The determination of the affinities of an extinct reptile, or other organism, affords a firm step to higher generalizations; and our obligations are truly great to Professors Marsh and Cope for the rich additions which their zealous endeavours have made to the materials for finally deciding upon the position which the extinct Mosasaurians held in the cold-blooded, air-breathing division of Vertebrates.

Discussion.

Prof. Seeley could not exactly recognize the Lacertilian type in the Mosasaurian limb, and thought that the proximal segment in the fossil, which was more likely to indicate affinities than the distal modifications, was not Lacertilian. He urged that while Prof. Owen had admirably elucidated the Lacertian affinities of these animals, they did not therefore of necessity belong to the Order Lacertilia; and, in view of structural differences in all parts of the skeleton, he considered it was at least a convenience to place them in a distinct Ordinal Group, as suggested by Prof. Cope.

Prof. Duncan thought that Prof. Cope had laid too much stress upon and ascribed ideal value to characters which could not be regarded as being, at best, of more than secondary value. He insisted on the important character of the possession of limbs by the Mosasaurs as strikingly distinguishing them from the Ophidia. He remarked further on the absence of a sternum, and on the Lacertian affinities of the sacrum, although he admitted the teeth had Ophidian

* *Op. cit.* p. 300.

affinities. He objected to the unnecessary multiplication of new Orders for the reception of fossil synthetic types.

Mr. Hulke thought that it was impossible to hesitate between the Lacertilia and Ophidia in fixing on the affinities of the Mosasauridæ, as the cranial and nearly all the characters were certainly very closely allied to those of the Lacertilia.

Prof. Owen, in reply, contended that even if the Mosasauridæ were the type of a new Order, yet the name of *Pythonomorpha* was an unfortunate and misleading one. By a comparison of the relations of the Order of Carnivora to the rest of the class of the Mammalia, however, he illustrated the inconvenience and confusion that would be produced in our zoological classification by raising such a group as the Mosasauridæ into a distinct Order.

42. *On the* QUARTZITES *of* SHROPSHIRE. By CHARLES CALLAWAY, M.A., D.Sc. Lond., F.G.S. (Read June 5, 1878.)

CONTENTS.

INTRODUCTION.

THE geology of South Shropshire, though it has received considerable attention from geologists, has been seriously misunderstood. This is owing partly to the disturbing influence of great south-west faults, partly to the obliterating influence of metamorphism, and partly to mistaken views of the causes of metamorphism.

In attempting to unravel the complexities of this disturbed area, I have arrived at some definite results, the first of which I communicated to this Society in a paper entitled, "On a new Area of Upper Cambrian Rocks in South Shropshire, with a description of a new Fauna" (See vol. xxxiii. p. 652, of the Quarterly Journal of the Society). In that paper I showed that a part of the so-called Lower Caradoc rocks south of the Wrekin were of the age of the *Dictyonema*-shales of Malvern and Pedwardine, and that a part of the so-called "quartzite" of the Wrekin consisted of Hollybush Sandstone. I deferred discussion on the true quartzites and on the igneous rocks of the district. The latter I hope to be able to prove in a future paper are only to a slight degree disruptive, and mainly consist of a great bedded* series of lavas and tuffs of Precambrian age. My second instalment of information is the announcement that the so-called Caradoc quartzites of the Wrekin and Church-Stretton area are of Cambrian or Precambrian age. In this connexion I shall notice the quartzites of the Stiper Stones, so as to include, so far as I know, all the quartzites of Shropshire.

A. WREKIN—CHURCH-STRETTON AREA.

1. *General Description.*

a. *Wrekin subarea.*—This district contains by far the largest

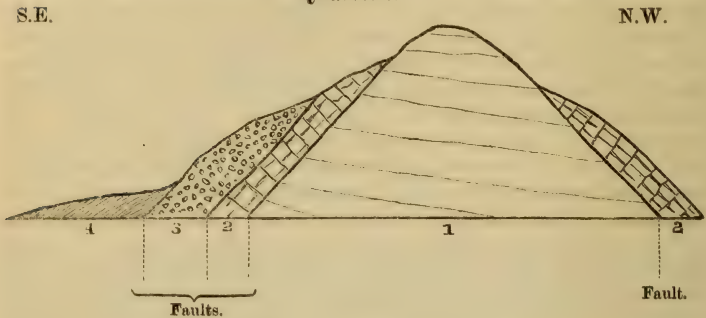
* The discovery of the bedded character of these rocks was made independently by Mr. S. Allport soon after myself, and was announced by him to this Society in May 1877, when he read a most valuable paper on their microscopic structure and composition.

horizontal development of the quartzites. They are finely exposed on the south-east side of the Wrekin range from its north-eastern extremity, half a mile south of Wellington, to its south-west end, a length of about three miles. The range is composed of three elevations, separated by two narrow gorges. The south-westerly, and by far the largest, mass is the Wrekin proper, and is $1\frac{3}{4}$ mile in length. The north-easterly hill, called the Ercal, is of less height than the Wrekin and of about half the length. The central hump, Lawrence Hill, is still lower, and occupies about a quarter of a mile of the length of the range. Throughout this paper I apply the name "Wrekin" to the Wrekin proper, the "Wrekin range" including also the Ercal and Lawrence Hill. This chain will be more fully described in my paper on the igneous rocks of the district. The quartzites rest against the volcanic axis in a nearly continuous band, striking to the south-west, parallel to the axis, broken by the above-named ravines, and apparently disappearing towards the summit of the chain. They reappear, however, towards the south-west end, and lap round the south-westerly spur of the mountain. I have taken numerous dips on the flanks of the Ercal, Lawrence Hill, and the Wrekin, and find that the direction of dip is on the average a little to the east of south-east, and its amount about 45°, ranging between 30° and 55°. Other exposures on the flanks of the range are scanty. An opening west of the south-westerly spur of the Wrekin shows a dip to the south-west. The inclination of the quartzite in all the above cases is *away from* the central axis, and is obviously due to its elevation. I have been unable to discover any exposures on the north-west side of the Wrekin. Under the summit of the mountain I can detect no traces of the quartzite; and this apparent break in the continuity corresponds in position with the disappearance of the rock on the opposite flank of the ridge. Further to the north-east of this point there is clear evidence of the quartzite in the shape of the ground, in the soil, and in the character of the vegetation. It here forms a buttress to the hill. The following section across the Wrekin (fig. 1) shows the position of this mass and of the quartzite on the south-east side of the axis. The section cuts the range at right angles at half a mile south-west of the north-east end of the Wrekin mass.

Keeping along the north-west side of the range towards the north-east, we next come to a small exposure of the quartzite cut through by the ravine separating the Ercal from Lawrence Hill. The section is too small and obscure for satisfactory determination; but the beds are apparently nearly vertical, with a slight tendency towards a south-east dip, that is, *towards* the axis. There is also a small mass of the rock at the north-east end of the Ercal, and in a line with the axis of the chain, but the dip and strike cannot be determined. Judging by the shape of the ground and soil indications, the quartzite is probably continuous all round the Wrekin range, with the possible exception of the two points under the summit on each side.

In the Wrekin-mass the quartzite does not reach the top of the ridge, even in its lower elevations, as illustrated in fig. 1, which cuts the range at more than half a mile to the north-east of the summit; but in the Ercal and Lawrence Hill the quartz-rock frequently rises to the level of the crest of the range, and at some points overtops it.

Fig. 1.—*Section across the Wrekin, showing the relations of the Quartzite.*



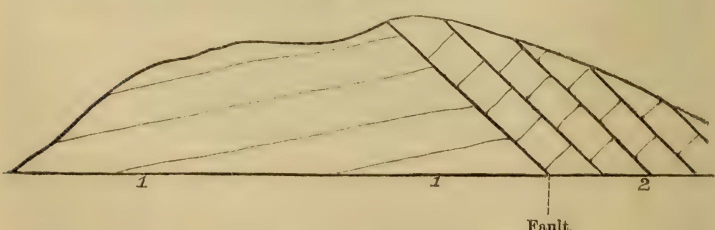
Scale about 8 inches to 1 mile.

1. Bedded Precambrian volcanic tuff, dipping north.
2. Quartzite.
3. Hollybush Sandstone.
4. Shineton Shales (Tremadoc).

The next section (fig. 2) illustrates the relation of the quartzite to the volcanic rocks in Lawrence Hill, and will equally well apply to the Ercal.

The quartzite is succeeded, as in fig. 1, by the Hollybush Sandstone.

Fig. 2.—*Section across Lawrence Hill, showing the position of the Quartzite.*



1. Bedded Precambrian volcanic tuff, dipping to the north.
2. Quartzite.

Looking down upon the Ercal and Lawrence Hill from the Wrekin, the line of the quartzite can be distinctly traced along Lawrence

Hill and onwards to the summit of the Ercal by the black colour of its soil. The decomposition of the volcanic rocks has given rise to a brown soil thickly covered with grass, shrubs, and trees. The disintegration of the quartzite, on the other hand, is so slight, that the rock, where it is not bare, which is frequently the case, has only a thin coating of black carbonaceous matter, which supports but a scanty vegetation.

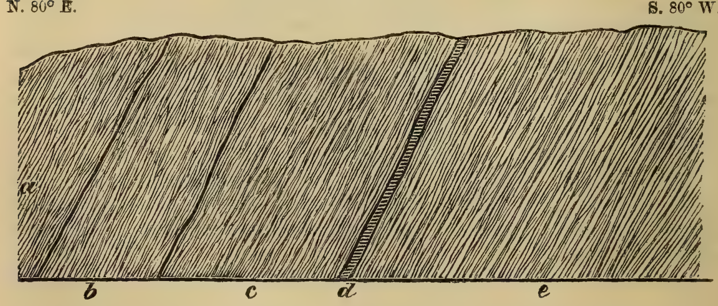
The thickness of the quartzite, measured at the north-east end of the Ercal, and in the last section (fig. 2), is about 200 feet.

Lying to the west of the Wrekin, and connected with the quartz-rocks just described by a narrow isthmus, is an irregular area of quartzite, 3 miles in length from north-east to south-west, and 1¼ mile in its greatest breadth. Through these strata are thrust up four bosses of bedded volcanic rock, the largest of which is Charlton Hill, with two small masses immediately to the south, and a larger exposure a mile to the south-west. The dips of these quartzites are very varied. In the road one third of a mile south of the spot marked "Charlton Mill" on the Ordnance map, they are displayed in a good section dipping south-easterly at 60°, and resting immediately upon igneous rocks. Two or three hundred yards to the north-east is quartz rock resting on porphyry of the Charlton-Hill boss, and dipping to the south at 45°. One third of a mile to the south of this last spot is another exposure of quartzite, dipping away to the south from the more southerly of the two small volcanic masses. A mile to the east-north-east of Charlton-Hill, at the village of Rushton, quartz-rock strikes north and south at a high dip; and a little to the north-west of Rushton the dip is westerly. One third of a mile east of Rushton, in the quarry marked with an arrow on the map of the Geological Survey, the quartzite dips to the south at 30°. These dips are too irregular to be referred to any one upheaving force. Wherever the quartz-rock occurs in close proximity to igneous rocks, it dips away from them; and it seems not improbable that other dips at a distance from exposed volcanic masses may be caused by local upheavals of volcanic rock which do not appear at the surface. In the map published with my previous paper (vol. xxxiii. p. 654), there is no exposure of Hollybush Sandstone indicated within this area; but recently I have detected a small opening of green sandstone, evidently Hollybush Sandstone, in the field to the south of the quartzite which dips to the south away from the most southerly of the three Charlton-Hill bosses. This sandstone dips to the north—that is, towards the quartzite, which is distant about 100 yards.

b. *Caer-Caradoc subarea.*—The quartzite reappears eight miles to the south-west of the last area, on the south-easterly flank of Caer Caradoc, near Church Stretton, an igneous hill of similar character to some of the Wrekin rocks, and evidently belonging to the same series. It is also less distinctly exposed at the south-west end of the south-east side of the Lawley, a volcanic hill north-east of Caradoc, and separated from it by a gap about a quarter of a mile in width. If the quartzite is continuous under the superficial deposits which lie in the gap, the band will be over a mile in length. At Caer Caradoc it is about 100 feet in thickness, and dips easterly at a high angle. At this part of the range a notch separates the main mass of the hill from its north-eastern prolongation, a much lower elevation, called Little Caradoc; and the quartzite is well seen the entire length of the south-eastern flank of the smaller hill, extends into the notch and partially overhangs its north-west side, and is seen for a short distance along the south-east side of the main mass. It can hardly extend much further to the south-west, since the Caradoc Sandstone soon appears in force, and is for many miles the lowest formation exposed on this side of the axis.

The quartzite is overlain by the Hollybush Sandstone, which is well-exposed in its lower part, dipping south-easterly at 75°; but towards the north-east end of the hill, the sandstone shows a tendency to lap round it, and dips to a little north of east. A short distance to the south-west higher beds of the series dip east-south-east at 35°. The Hollybush in places is highly quartzose, with grains of green earth and decomposed felspar, and is almost undistinguishable from certain parts of the basement beds of the Caradoc which appear against the same side of the axis a mile to the south-west. This similarity doubtless helped to mislead the earlier surveyors, and is paralleled by the equally confusing resemblance between the Shineton and Harnage Shales, which I pointed out in a previous paper *. These sources of difficulty, together with overlaps, inversions, and numerous and heavy faults, render the district a perfect maze of perplexity. Happily, the identity of the sandstones is clearly established by the following section, which is exposed in a quarry at the north-east end of Little Caradoc.

Fig. 3.—*Section of Hollybush Sandstone at the north-east end of Little Caradoc.*



The beds *a* are ordinary Hollybush Sandstone, consisting of rounded grains of a felspathic mineral and of green earth, with a little mica. At *b* the rock is more quartzose, and decomposition is more advanced. The underlying beds (*c*) are conglomeratic, the pebbles

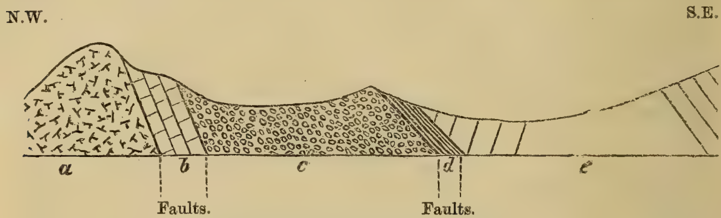
* Quart. Journ. Geol. Soc. vol. xxxiii. p. 653.

being of quartz, with a matrix of quartz, green earth, and felspar. The beds *e* are the ordinary green sandstone. The thin band *d* deserves more attention. It is less than 1 foot in thickness, and is a dark-coloured compact limestone. Associated with it is a little red shale, and near the surface of the bed the limestone assumes the same colour. This band is very fossiliferous, the most abundant form being apparently trilobitic; but it occurs in such a fragmentary condition, and is of such an unusual type, that I cannot express any opinion on its generic affinities. Brachiopoda are not uncommon: two or three species are undeterminable, save that they belong to the Tretenterata. One form, a minute roundish Lingulid, is apparently new. What is of more importance for our purpose is that the bed contains two well-known Malvern species, *Kutorgina cingulata*, Bill., and *Serpulites fistula*, Holl, both of which are found in the same formation on the flanks of the Wrekin. The Hollybush Sandstone is thus shown to overlie the quartz-rock, as in the Wrekin district. It is about 300 or 400 feet in thickness, and extends to the south-west for some distance; but I have not traced it quite so far as the quartzite. Indeed the exact limits of both formations are not ascertained, the exposures towards the south-west being very few and slight.

I have had the good fortune to discover the presence of the Shineton Shales in their true place above the Hollybush Sandstone of this subarea. They are seen in the road leading up from the gap towards Shoots Rough. The width exposed represents a thickness of about 30 feet, and the dip is east or east-south-east apparently at 35°. They are succeeded by the Hoar-Edge grits (Lower Caradoc), which plunge towards them at an angle of 60° or 70°. In the Shineton district the shales are apparently conformable to the overlying Caradoc, and the chief evidence for the greater antiquity of the former is derived from fossils. Here, however, the two formations are separated by a fault, which must be of considerable throw, since, as I have reason to believe, neither the upper part of the shales nor the lower part of the sandstone is represented. Following the shales on the line of strike to the north-east into the ravine between the Lawley and the sandstone escarpment of Hoar Edge, where the escarpment approaches to within a quarter of a mile of the hill, we find them well exposed on the stream, dipping to the east at an angle of 50°, which probably represents the true dip more accurately than the shallow road-section. I have detected in them *Lingulella Nicholsoni* and Shineton Graptolites. From their general appearance, and from the presence of Graptolites, I infer that these beds belong to the middle part of the series. There are slight indications, in the shape of the ground and in the soil, that the shales run parallel to the Hollybush towards the south-west, where both are cut off by the Hoar-Edge grits (Caradoc).

The quartzite, Hollybush Sandstone, and Shineton Shales thus appear to succeed each other in conformable succession; but, from the relations of the three groups at the Wrekin, from the number of parallel faults which traverse the area, and from other considerations, I cannot believe that the conformity is real. The following section (fig. 4) will illustrate the succession which I have just described.

Fig. 4.—*Section across Little Caradoc and valley to the South-east.*



Length of section about half a mile.

a. Syenite of Little Caradoc. *b.* Quartzite. *c.* Hollybush sandstone. *d.* Tremadoc (Shineton shales). *e.* Caradoc.

c. *Cardington subarea.*—A little over a mile from Caer Caradoc to the south-east is an abrupt ridge of quartzite called the Sharp Stones, dipping to the north at from 40° to 50°, and striking east and west for about half a mile. It rests upon the bedded volcanic rocks of Cardington Hill, and is evidently tilted up by the elevation of that mass. Succeeding it to the north is Caradoc Sandstone, with its usual south-west strike, apparently unaffected by the upthrust of the older rocks, and probably separated from the quartzite by a fault.

2. *Relations of the Quartzite to the associated Rocks.*

Along the south-eastern flanks of the Wrekin range, the quartz-rock rests upon the bedded tuffs and felstones of the volcanic nucleus unconformably, the igneous rocks dipping north, while the quartzite dips south-east. Towards its base the quartz-rock contains fragments derived from the older series, consisting of small rounded or unrounded pieces of felstone greatly decomposed, but in some cases showing distinctly the banded structure characteristic of some of the Wrekin felstones. At its base the quartzite is brecciated, both the fragments and their cement being quartzose, with the occasional occurrence of barium sulphate. This breccia can be traced along the line of junction through the Ercal, Lawrence Hill, and some distance along the south-eastern flank of the Wrekin. There are also signs of brecciation on the opposite side of the range, near the ravine between the Ercal and Lawrence Hill. This breccia may be a friction breccia, caused by the upthrust of the rigid mass of volcanic rock which forms the backbone of the range; and the fact that the breccia is not derived from the rock upon which it rests favours this conclusion. There is thus reason to conclude that the plane of junction between the younger and older series is a fault. I have not observed the breccia in other parts of the Wrekin (Church-Stretton) area, except at the quarry east of

Rushton; but, as the igneous rock of the entire district is mainly bedded, it seems impossible that bosses of it could be pushed up through overlying beds without producing faults. The relations of the quartzite to the older igneous series appear to be similar to the above in both the Caer-Caradoc and the Cardington localities, with the possible exception of one spot at the north-east end of Caer Caradoc, where the nucleus of the range consists of syenite. This syenite may be disruptive, but at any rate it does not affect the general strike of the overlying quartzite.

As the quartzites are limited by faults on the underside, so I conclude that in most cases, probably in all, they are separated by faults from the strata which overlie. In the Wrekin area, the rock in immediate contact with the quartzite on the opposite side from the underlying volcanic strata is the Hollybush Sandstone. Fig. 1 shows this relation. I have given reasons in a previous paper * for believing that the Hollybush is separated from the quartzite by a fault in this locality, and shall refer to the subject further on. In the outlying Charlton-Hill district, the only spot in which I have detected the Hollybush is the one to which I have already referred, where the dip is towards the quartzite. Here also there must be a fault. At Caer Caradoc, as shown in fig. 4, the Hollybush appears to succeed the quartzite conformably. At the Sharp Stones, the upper boundary of the quartz-rock is a fault separating it from the Caradoc. The quartzites would thus appear to be bounded both above and below by faults. These dislocations will appear less difficult of belief when we bear in mind the disturbing influence of the Church-Stretton and associated faults. When we find Wenlock rocks wedged in between Lower Cambrian and Precambrian in one spot, and between faulted masses of Caradoc in another, and when, as in the Harnage district, we see the Hoar-Edge Grits lying at a right angle upon the upturned edges of younger strata, we shall be surprised at no hypothesis, however eccentric, which rests upon a reasonable basis of facts.

3. *The Age of the Quartzites.*

The quartzite is certainly older than the Hollybush Sandstone, for, in every observed case, the sandstone rests upon the quartz-rock, or is at least outside of it with regard to the axis of elevation. This is well seen in the Wrekin subarea, and still more distinctly on the south-east flank of Caer Caradoc (fig. 4).

But the age of the Hollybush Sandstone must first be determined. It is commonly placed upon the horizon of the Ffestiniog group, on the ground that it underlies the Black Olenus Shales of Malvern, which are with great probability correlated with the Dolgelly series. But the relations of the Hollybush and Black Shales are very obscure, and it has not been shown that they succeed each other conformably. Mr. Belt considers the Hollybush to be a shore deposit of the Menevian sea; but I am willing to accept the former

* Quart. Journ. Geol. Soc. vol. xxxiii. p. 662.

determination till decisive evidence is forthcoming. The quartzite, then, is older than the Ffestiniog period. But the Hollybush and the quartzite do not succeed each other conformably. In the Wrekin area the dips are so discordant as to suggest a considerable gap. The quartzite, in most cases, dips away from volcanic bosses, and the direction of dip is determined by these local upheavals. But the dips of the Hollybush are subject to no such law. Their general direction on the south-east of the Wrekin, where the quartzite dips south-easterly, is to the south-west; but in one place they appear to conform to the dip of the quartzite, and at a little distance they plunge at a high angle to the north-west (that is, towards the quartzite). South of Charlton Hill, also, the sandstone dips towards the quartzite. The apparent conformability of the two formations at Caer Caradoc cannot counteract such clear evidence of discordance. Parallelism of strike does not prove conformity, since a strike fault might let down the upper of the formations without producing any alteration in the dip or strike.

It is clear, therefore, that the quartzite is older than the Hollybush Sandstone by a gap, and, consequently, cannot belong to any part of the Upper Cambrian series.

Three hypotheses now remain. The quartzite may be on the horizon of the top of the Lower Cambrian; or it may belong to the Lower Cambrian, or it may be Precambrian.

a. *The top of the Lower Cambrian* (*Longmynd series*).—The Lower Cambrian of Shropshire, as is well known, is a great series consisting of fine-grained slates or hardened shales in the lower part, and of sandstones and conglomerates above. For reasons which I cannot here detail, I believe that neither the base nor the top of the succession is seen, being cut out by faults. Does the quartzite represent a lost capping of the Longmynd rocks? I think the great discordance between the quartz-rock and the Hollybush Sandstone decisively negatives this supposition.

b. *The Longmynd Series.*—No band of quartzite has been observed in this series from top to bottom. If the quartz-rock represents any part of the Longmynd succession, where are the beds which on this supposition should intervene between the quartzite and the Precambrian volcanic series? Or is the quartzite a basement of the Longmynd rocks? If so, there should surely be some concordance of dip and strike. But the Longmynd strata in their lower part almost uniformly dip at very high angles to the west-north-west, whereas the quartzite, as previously shown, dips away from volcanic bosses at the most varied dips and strikes.

c. *Precambrian.*—On the rejection of hypotheses *a* and *b*, the balance of probability is decidedly in favour of this supposition.

4. *The Fauna of the Quartzite.*

For years I searched for fossils in vain; but since I commenced this paper I have detected on the south-east flank of the Wrekin, near the cottage, one good specimen of a worm-burrow, apparently

Arenicolites, and portions of one or two more. The burrow is a simple loop, resembling a letter U, 2 inches in length by 1 inch in breadth. I would propose for it the name *Arenicolites uriconiensis*. If my view of the age of the quartzite is correct, this specimen is, with the exception of the problematical *Eozoon*, the oldest known fossil.

B. The Quartzite of the Stiper Stones.

The physical characters of this rock have been so well described by Murchison ('Siluria,' cap. iii.), that it will be unnecessary to make additional observations. I have but to add a suggestion on its geological age. By the author of 'Siluria,' it is placed on the horizon of the Lingula Flags, on the ground that it is below the Llandeilo, and contains worm-burrows and fragments of a Lingulid, which, it is candidly stated, does *not* resemble *Lingulella Davisii*. Geologists of the present day will hardly be disposed to accept such evidence as conclusive. The shales overlying the quartz-rock contain *Illœnus perovalis*, *Calymene parvifrons*, *Æglina*, *Placoparia*, and other Arenig forms. There can therefore be little doubt that the quartzite is of Arenig age, and, consequently, quite distinct from the quartzite of the Wrekin area. The two rocks can generally be distinguished from each other even in hand specimens; and, when they are conglomeratic, the pebbles of the Arenig quartzite mainly consist of quartz, while the included fragments of the Wrekin quartz-rock are felsitic.

Note.—Since writing the chief part of this paper, I have detected the Shineton Shales in force at the base of the escarpment of the Stiper Stones, and dipping under the Arenig series in the same direction as the rocks of that formation—that is, west-north-west. The plane of separation appeared to me on a hasty inspection to be a fault. This supplies additional proof of the Tremadoc age of the Shineton Shales, and of the separation of the underlying Wrekin quartzites from the overlying quartzites of the Stiper Stones.

Discussion.

Dr. Gwyn Jeffreys doubted whether the boring had been that of an Annelid, especially as the rock was not calcareous.

Mr. Etheridge expressed his agreement with the position assigned to the Hollybush Sandstone in the area described by the author, and thought that the results of the paper were of great interest and value.

Dr. Hicks thought that the burrow was very like one in the Stiper Stones and in similar sandstones in Scotland, and that the quartzites were hardly so old as the author supposed; but he agreed with the author as to the probably Precambrian age of the volcanic group.

Mr. Callaway responded, giving some explanation of the apparent difficulties in the sections, which were to be explained by faults. In reply to Dr. Hicks, he held that the stratigraphical position of the quartzite was far more decisive than lithological resemblance or the similarity of Annelid-burrows.

43. *On an* Unconformable Break *at the* Base *of the* Cambrian Rocks *near* Llanberris. By George Maw, Esq., F.L.S., F.G.S., &c. (Read April 3, 1878.)

The short paper which I have to lay before the Society has been suggested by several previous communications on the subject of rocks older than, and unconformable to, the Cambrian Slates of North Wales.

In the year 1867 I brought before the British Association at the Dundee meeting the accompanying section on the Llanberris and Carnarvon Railway, then for the first time exposed in a new cutting near Llanberris. The section was subsequently published in the 'Geological Magazine' for March 1868, to which I must refer the reader.

Up to this time no suspicion existed of the occurrence of an unconformable series of ancient rocks in North Wales older than the Cambrians.

Previous to this the researches of Dr. Hicks in Pembrokeshire established in that district the fact of the occurrence of great series of beds unconformable to the overlying Cambrians; but during the succeeding seven or eight years no fresh observations were made in the Llanberris district.

At the reading of Dr. Hicks's paper on December 2, 1874, I pointed out an apparent analogy between the Pembrokeshire series and that at Llanberris; and this, I believe, induced Professor Hughes and Dr. Hicks to visit Llanberris, and their observations on that district were recently communicated to the Society (Q. J. G. S. vol. xxxiv. pp. 137 & 147).

Rather singularly, they disagree with me in the conclusion I arrived at, that there was a visible break in the series of rocks exposed in the Llanberris railway-cutting, but admit that such a break does occur at Moel Tryfane, where the unaltered Cambrian slates rest unconformably on the adjacent altered rock.

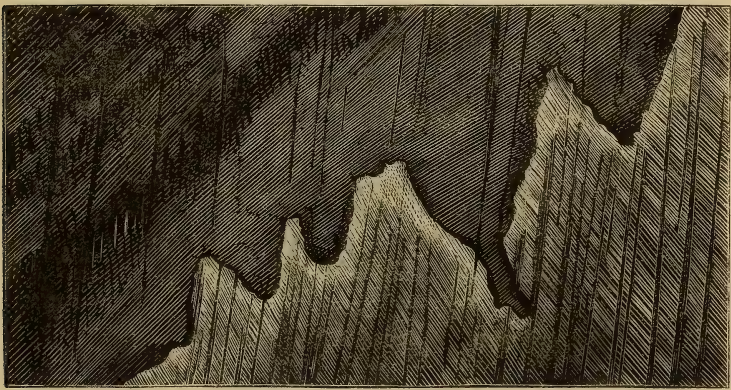
It is unquestionable that both series are identical, and include the same succession of rocks; and if the unconformity exists at Moel Tryfane it must also appear on the banks of Llyn Padarn, where a fairly continuous section is exposed in the cuttings.

The substance of what I recorded in 1867 was to the effect that the Cambrians of Llanberris do not pass into the great metamorphic mass of porphyritic rocks crossing the north-west end of Llyn Padarn (marked "Felspar-Porphyry" in the Survey map), but that they rest unaltered and unconformably on a more ancient series of distinctly stratified rocks which graduate into the metamorphic mass, having near Betwys Garmon a distinct igneous nucleus.

I had the good fortune, in 1867, to see the section when freshly exposed, which enabled me to note all the details from careful and exact measurement. Ten years weathering has partly obscured them, but the most important feature, the unconformable junction of the Cambrian grits with an underlying series of more ancient rocks, is still plainly visible at a point 75 feet on the Llanberris side of the eighth railway milestone.

The section published in the 'Geological Magazine' for March 1868, so far as my own observations go, includes two distinct series of rocks—those to the left or south-east (excepting perhaps a few yards at the south-east end of section) consisting of Lower Cambrian grits with a dip and strike corresponding with the lie of the workable slates of the Glyn Quarries, portions of which are here and there faulted down amongst the grits. Those to the right or north-west end of the cutting consist of a synclinal of brindled slates, banded grits, and conglomerates, which gradually pass into the great mass of grey porphyry-like rock crossing the north-west end of Llyn Padarn.

Junction of Cambrian Grits resting on Lower Series.



The nearly vertical lines represent cleavage.
The oblique lines the stratification of shales.

The above figure represents, on a larger scale than that of my general section, the point of junction of the two series, where the obscurely banded Cambrian grits rest unconformably on the edges of an older slate at the south-east end of the synclinal.

The slates of this lower series differ in character from the workable slates of the Glyn Quarries, being more shaly, and are brindled with pale bands and patches, less defined than the distinct pale blotches and stripes in the workable slates.

In both series cleavage and stratification are easily distinguishable, and no possible mistake can be made through confounding them: indeed the stratification of the lower series is well defined in the alternation of conglomerates and grits with the slates, as well as by the sudden bends and rolls that occur in the banded slates.

Professor Hughes, in his recent paper, pointed out the unconformity of the Cambrian series with the great porphyry-like mass north-west of Moel Tryfane, though he disputed the existence of a break in that part of the series included in the Llanberris railway-cutting.

Now I believe that both may pertain to the same break in the sequence; that the beds included in the synclinal at the north-west end of the cutting are the unaltered portion of the great metamorphic porphyry-like mass at the lower end of the lake into which they graduate; and that towards Moel Tryfane these are overlapped by the Cambrians, which rest unaltered against the metamorphic mass. The synclinal of what I believe to be rocks older than the Cambrians is repeated on the north-east side of the lower end of Llyn Padarn, graduating, as on the south-west side, into the metamorphic grey rock.

The continuity of sequence between the stratified synclinal and porphyry-like rock is evident from the occurrence here and there in the latter of thin beds of slaty rock following the dip of the beds at the north-west end of my section, though stratification has been obliterated in the intercalated porphyritic mass.

Knowing that it is often difficult in the older cleaved rocks to distinguish cleavage from stratification, I have, within the last few days, revisited Llanberris to test the observations I made in 1867, and I can only confirm the conclusions I submitted to the British Association at the Dundee meeting; and I cannot agree with Professor Hughes that the appearance of unconformity in the cutting can be explained by any peculiarity of rock-structure. The singular line of separation clearly defines the underlying slates dipping in one direction and the unconformable overlying grits in the other. The relative direction of the stratification of the two series is perfectly clear and unmistakable, and cannot be confounded with cleavage, which also occurs, but in a different direction to the stratification.

If, as I believe, the conclusions I have arrived at will be verified by other observers, I may claim for the Llanberris railway-section some importance in the history of the classification of the older rocks of Wales, as, ten years ago, no unconformable break was known to occur at the base of the Cambrians in North Wales, though the previous observations of Dr. Hicks in the St.-David's district, and those of Professor Hughes subsequently made in the near neighbourhood of the Llanberris Railway-section, have established the fact of the existence of an unconformable series of older stratified rocks.

Discussion.

Dr. Hicks said that Mr. Salter and himself had published their conclusions as to the existence of pre-Cambrian rocks at St. David's as early as 1864. He added that, in company with Prof. Hughes, he had visited the North-Wales district, and although he had previously been inclined to accept Mr. Maw's interpretation, yet on a critical examination of the appearances presented by the section he was unable to admit the existence of the unconformity at the point where it was placed by the author. He argued that the appearances described by Mr. Maw were not such as are usually exhibited in cases of unconformity, in which we may expect to find evidence of elevation and denudation and the formation of littoral deposits, composed of pebbles derived from the older rocks, at the line of junction of the two series.

Prof. Hughes defended the view expressed in his paper read before the Society in December, pointing out that the supposed unconformity occurred in the middle of the well-known green schists and sandstones which formed the lowest Cambrian beds, and not at the base of any well-marked group; that the jagged edge of the slate was not the kind of surface likely to be left by such a denudation as must have taken place at the commencement of the Cambrian period; and that there was no conglomerate or other evidence of such denudation along that line. He considered that the divisional planes below the supposed unconformity, which Mr. Maw took for bedding, were due to cleavage.

Prof. Ramsay stated that the section referred to by the author, which was exposed in a railway-cutting, was examined by himself and Prof. Huxley with the assistance of Mr. Maw's own drawings, and that they both came to the conclusion that there was no proof of an unconformity such as that insisted on by the author. He maintained that there was a natural passage from the quartz-porphyries up through the conglomerates into the beds lying above them, and denied the possibility of separating the pebbles imbedded in the conglomerates in the manner which had recently been described. After a long and careful study of the junction, he had come to the conclusion that there was a gradual passage between the two series, as stated in his 'Geology of North Wales,' a new edition of which will shortly be published. Hence he was led to regard these masses of quartz-porphyries as representing rocks of Cambrian age excessively metamorphosed through pressure in the manner which had been suggested by Mr. Mallet and himself.

Prof. Seeley indicated that a crucial test to which the views of Mr. Maw and those of his critics might be subjected would be afforded by examining if the planes of cleavage in the lower rocks passed into those above.

Prof. Hughes, in reply to Prof. Seeley, stated that the cleavage, though less strongly marked among the sandy beds, distinctly occurred above and below the supposed unconformity.

Prof. Ramsay said that both porphyries and slates were traversed by the same divisional planes.

The President, without wishing to prejudge the question, remarked that the drawings exhibited by the author greatly resembled the appearances presented in some undoubted cases of crumpling and distortion by cleavage.

The Author, in reply to Mr. Hicks, said that his remarks about priority of observation referred only to North Wales, where he had been the first to suggest, in 1867, the existence of a series older than the Cambrians, and this had led to the subsequent researches of Professor Hughes and Mr. Hicks in the same direction. If, as Mr. Hicks had stated (with which the author agreed), the Cambrians of Moel Tryfane rest unconformably against the quartz-porphyry mass, the same unconformity must exist in the Llanberris railway-cutting, as it includes an almost continuous section from the workable slates of the Glyn quarries to the quartz-porphyry at the N.W. end of the lake; after a reexamination of the line of junction on three different occasions, he could find no other interpretation of the section in question than that of an unconformable break in the series. He maintained that the stratification of the two sets of beds was clearly visible, and was quite discordant in the two cases, and also readily distinguishable from the planes of cleavage, which were in a different direction from the stratification of both series. Even supposing that the sinuous line of junction was partially due to crumpling, the author considered that such interlacing and distortion might as readily occur between beds in unconformable contact as within evenly stratified deposits.

44. *On the* SERPENTINE *and associated* IGNEOUS ROCKS *of the* AYRSHIRE COAST. By Rev. T. G. BONNEY, M.A., F.R.S., Sec. G.S., Professor of Geology at University College, London, and Fellow of St. John's College, Cambridge. (Read May 22, 1878.)

CONTENTS.

Introductory.

IN the twenty-second volume of this Journal is a paper by Dr. J. Geikie on the metamorphic Lower Silurian rocks of Carrick, Ayrshire. The author endeavours to prove that the rocks of the district, with some few slight exceptions, are of sedimentary origin, a "felspar porphyry" being the "maximum stage of metamorphism exhibited by the felspathic rocks of the district." The "dioritic rocks," "diorite and hypersthenite, both of which are occasionally foliated," are also regarded as of metamorphic origin; and, lastly, the "compact serpentines, like the altered strata with which they are associated, are truly bedded rocks." This view is also very clearly enunciated in the 'Descriptive Catalogue of Rock Specimens collected by the Geological Survey of Scotland, and exhibited in the Edinburgh Museum of Science and Art' (ed. 1870), p. 49 &c., from which I quote a few sentences. "The altered rocks of this district may be grouped into three classes—felspathic rocks, dioritic rocks, and serpentine. The felspathic rocks are by far the most abundant, and vary much in structure and aspect; the diorites and serpentine have a more definite character, and are often interbedded or closely associated. But the one class shades into the other, and no strongly marked line of division between them can be drawn upon a map. The metamorphic changes which have affected these Lower Silurian strata can hardly be exhibited in hand specimens, but must be studied in the field."

The paper referred to above was severely handled on chemical and mineralogical grounds by the late Mr. D. Forbes*; it is, however, quoted in text-books† as establishing the above conclusions. These, however, Mr. Forbes's criticisms and my own work in various localities have long made me hesitate to accept‡; and about two years since my scepticism was increased when Mr. S. Allport showed me some specimens of serpentine from the vicinity of Colmonell, and

* Geol. Mag. vol. iv. pp. 49 & 225.

† *E. g.* Jukes and Geikie, p. 142; Green, pp. 292, 295.

‡ The late Sir R. I. Murchison, who described this district (Quart. Journ. Geol. Soc. vii. p. 137), declined, as I find (Siluria, p. 155, ed. 1867), to abandon the idea of the igneous origin of some at least of these rocks.

expressed grave doubts as to the correctness of Dr. Geikie's reading of the petrography of the district. One of the serpentines among these specimens could not have been distinguished from a variety from the Lizard. Accordingly I determined to examine them as soon as I had finished my Cornish work. This I did in July 1877, and had the advantage of being accompanied by my friend the Rev. E. Hill, who had been my companion during my last visit to the Lizard. I am allowed to say that he quite concurs with my interpretations of the sections. On returning home I had a series of slides prepared from the more important specimens which I had collected, and some chemical analyses have been kindly made for me by F. T. S. Houghton, Esq., B.A., Scholar of St. John's College.

We drove from Girvan to Colmonell by the coast road as far as Lendalfoot; the result of this journey and of an afternoon's walk inland was to convince me that here, as in Cornwall, the relations of the rocks would be most clearly demonstrated on the sea-shore, cultivation and vegetation making it almost hopeless to obtain good sections inland. We accordingly worked the coast carefully from Balcreuchan Port to Pinbain Hill (about 4½ miles), the only part where the serpentine reaches the shore. The result has been that I find myself, as will appear, in several important respects, quite unable to accept Dr. Geikie's interpretation of the petrography of this part of Ayrshire.

Serpentine of Balhamie Hill.

Before proceeding to the shore-sections I will briefly describe the serpentine of Balhamie Hill, near Colmonell, which can be well examined in a pit near the roadside, about three quarters of a mile from the village. This rock can hardly be distinguished from the black serpentine north of Cadgwith, Cornwall*. It has exactly the same sharply defined but rather irregular rhomboidal jointing. The joints are coated with greenish or whitish steatite, often show slickensides, and turn brown after exposure to the weather. The rock itself, on old surfaces, assumes the same rugged grey-brown aspect as that at the Lizard; its fracture is subconchoidal. The ground-mass is a deep black, weathering to a pale grey-green. It is full of crystals of glittering bronzite †, just like those in the Cadgwith rock. A detailed description of the microscopic structure is needless; for what I have written of that will apply here almost word for word, the only difference being that, in the specimen examined, the conversion of the olivine into serpentine is complete. The "strings" of doubly refracting serpentine, stained and clothed with granules of black ferric oxide, exhibit a rude parallelism over part of the slide. The bronzite also in this rock is a little more altered than it is at Cadgwith; some grains contain numerous fer-

* Quart. Journ. Geol. Soc. xxxiii. pp. 899, 921, 925.

† I mean by bronzite the variety of enstatite which has a metallic lustre. In my paper on the Lizard I avoided the former term, as it had often been used indefinitely by English authors, and I wished to call special attention to the fact that the Cornish mineral was not diallage.

ruginous microliths. There is in the slide a grain or two of a dark brown mineral, possibly picotite. I have not the slightest doubt that this is an altered olivine-enstatite rock.

The following is Mr. Houghton's analysis of the "serpentine freed from enstatite;" and I reprint, in a parallel column, that of the Cadgwith serpentine by Mr. Hudleston (*loc. cit.* p. 925). A comparison of these will show how closely they correspond.

	Balhamie. (Dried at 100° C.)	Cadgwith. (Dried at 100° C.)
Water	14·08	12·35
Iron sulphide	trace	0·41
Silica	38·29	38·50
Alumina*	3·95	1·02
Iron sesquioxide	2·53	4·66
Iron protoxide	4·04	3·31
Lime	0·57	1·97
Magnesia	35·55	36·40
Manganese oxide	trace	. .
Nickel oxide	0·15	0·59
Residue	. .	1·37
	99·16	100·58

In the quarry is seen an irregular vein of a greenish mineral, not exceeding about 4 inches thick. Mr. Houghton reports as follows:—"Amorphous, hardness about 3; S.G. 2·87. It is fusible at the blowpipe with some difficulty. It is entirely decomposed by hydrochloric acid, leaving the silica in a pulverulent condition.

"Its composition is as follows:—

H_2O	9·52
CO_2	traces.
SiO_2	33·13
Al_2O_3	17·63
Fe_2O_3	0·30
FeO	6·57
MnO	traces.
CaO	10·31
MgO	21·26
	98·72

* The percentage of alumina is rather large, but there is certainly no felspar present or any other mineral akin to it. Perhaps the difference between the two rocks in this respect may be thus explained: the bronzite in the Balhamie rock is more altered than in that from Cadgwith, and so a less quantity may have been separated from the serpentine by the method employed. Mr. Hudleston found that there was a fair amount of alumina present in the Cadgwith bronzite, and so there probably is in that of Balhamie. Hence the amount of alumina present in the serpentine proper is probably rather less than appears in the analysis.

"This rock appears to coincide in all its properties, both chemical and physical, with the mineral chonicrite, which is stated by Dana (Min. ed. 1868, p. 494) to be found associated with serpentine in Elba. It differs in having less Si and more Fe."

The commonest rock on the shore near Lendalfoot is serpentine, which, with occasional intervals of sand &c., extends for about one mile to north and two and a quarter to south of that hamlet. Together with it (according to Dr. Geikie) the "dioritic" rocks appear "interstratified as small lenticular layers. The principal varieties are diorite and hypersthenite." I will retain the term "dioritic" for convenience of reference, excluding the latter variety.

The "Dioritic" Rocks.

As in the case of the hornblende schists of Cornwall it was no part of my plan to examine into the lithology of these rocks after I had once settled their relation to the serpentine. Some of them certainly appeared to be metamorphic stratified rocks; others, however (especially some porphyritic varieties), struck me as having a remarkably igneous aspect, so I collected two or three specimens of these for microscopic examination, thinking they might illustrate extreme metamorphism. I now regret that I did not more minutely observe the details of this series, for I find that these examples are igneous rocks; they contain very characteristic and well-preserved augite, but no hornblende, and show the usual structure of a dolerite. The following is a brief description of the four specimens which I selected for microscopic examination *.

(1) Specimen collected from mass about 200 yards north of Lendalfoot cottages (porphyritic in places) contains much well-preserved augite, some viridite (serpentinous variety) probably replacing olivine, and exhibits the general structure of a dolerite, though the plagioclase has lost its characteristic appearance and is replaced by pseudomorphous products of a granular to rather fibrous structure, showing bright colours with crossing Nicols. I suspect more than one zeolitic mineral is present, but cannot venture to identify them.

(2) Specimen from mass included in serpentine about 100 yards south of skerry at back of cottages, Lendalfoot, exhibits a few augite crystals, very well preserved, in a ground-mass composed of small grains of augite and crystals of plagioclase (highly altered, earthy, and semiopaque), together with ferruginous granules. Some of the small grains of augite have a rather fibrous aspect, are iron-stained, and exhibit dichroism. Much of the ferruginous mineral resembles altered ilmenite. It is difficult to speak positively, but I believe this is only an altered dolerite.

(3) Specimen from a porphyritic variety with large crystals of white plagioclase, south of Lendalfoot (I believe the one mentioned by Mr. Geikie, *loc. cit.* p. 526, as a felstone which "illustrates how

* I may state that the pectolite which is associated with some of the rocks in this series is a very beautiful microscopic object with crossing Nicols. I think that I noticed in it the optical character which is mentioned by Prof. Dana ('Text-book of Mineralogy,' p. 315).

a felstone becomes a diorite"). That this is a dolerite there can, I think, be no doubt. The structure is very characteristic; the plagioclase felspar, both in the large and small crystals, though often rather altered, is clearly recognizable; the augite is perfectly distinct. There is an iron peroxide, probably ilmenite, a greenish serpentinous pseudomorph probably replacing olivine, and perhaps a little apatite *.

(4) Specimen from a reddish variety, with porphyritic crystals of white felspar, from road-cutting south of Carleton Port Point. Though much iron-stained, I think there can be no doubt of the doleritic character of this rock; plagioclase and augite can still be clearly recognized, though in parts both are more or less replaced by secondary products. A vein of zeolite (? pectolite) crosses the slice.

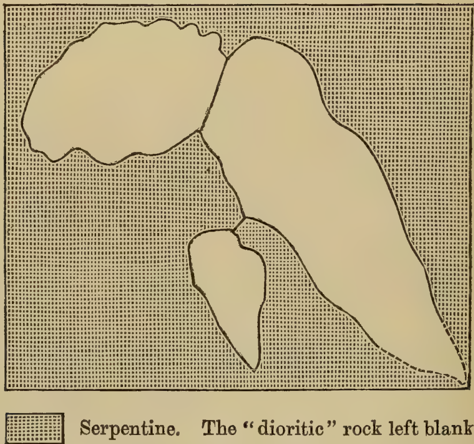
I also selected two specimens of a compact black rock representing another common variety. At that time, not having realized how slight was the evidence of extreme metamorphism, I thought this might be some kind of highly altered "mudstone," though in some respects it much resembled a compact basalt. After microscopic examination I have little doubt that it has been a basalt with a microcrystalline or perhaps glassy base. The structure of one is not very distinct, as the specimen was taken from close to a junction with the serpentine, and the exterior of the specimen has become of a greyish colour (as is common with basalts); but still many small decomposed plagioclase crystals, and a little minute augite, can be seen, and the microscopic structure is far more like that of a "white trap" than any sedimentary rock known to me. Before the blowpipe it fuses easily to a black glass. The other is a section of one of some curious protuberances on the face of some of the rocks near Lendalfoot, at first sight almost like an amygdaloid (except that it seems formed of the rock itself, which resembles the last). This also can, I think, be nothing but a glassy basalt. The usual pseudomorphs have replaced the felspar, and the augite is rather altered, but a little is still fairly characteristic. On the inner side of the slide the rock is more crystalline. No doubt some of the rocks of the district are of sedimentary origin; but, as far as I remember, the majority of those near Lendalfoot resemble the above. They accordingly do not favour the idea of extreme metamorphism, and do not contain hornblende, but augite; hence the epithet dioritic is inapplicable. If, however, I am able to revisit the district, I purpose to examine this series much more in detail, in order to separate the igneous from the altered rocks; for the latter are undoubtedly present.

* Some of the larger felspar crystals contain numerous minute microliths of a resin-brown colour; their forms seem to be a very short prism of hexagonal or octagonal section, but this is commonly not well defined. In general form they much resemble crystals of the first system; but they are certainly doubly refracting, and, I think, not uniaxial. The mineral appears to be the same that I have observed in the felspar of other basalts (*e. g.* some of those from Arthur's Seat), and is probably augite. Prof. Rosenbusch ('Mikroskop. Physiographie,' vol. ii. p. 461) describes a mineral which appears to be similar to this, and thinks it may be rutile. This, however, is, of course, uniaxial.

The Serpentines of the Coast.

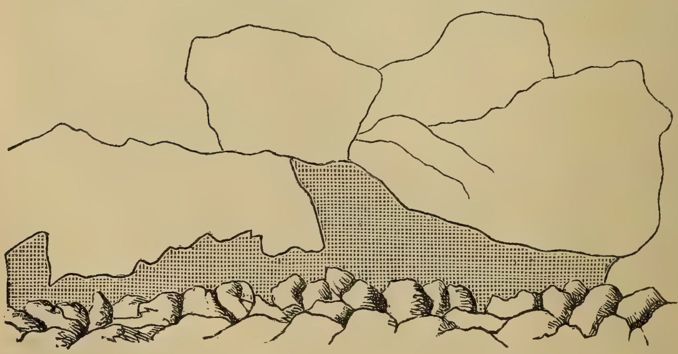
To settle the petrological relations of these rocks to the "dioritic" group it is hardly necessary to go beyond the vicinity of Lendalfoot. For example, just at the back of the cottages is a great mass of the "dioritic" rock, apparently included in the serpentine (fig. 1). The

Fig. 1.—*Plan of Dioritic Rock in Serpentine, Lendalfoot.*



Serpentine. The "dioritic" rock left blank.

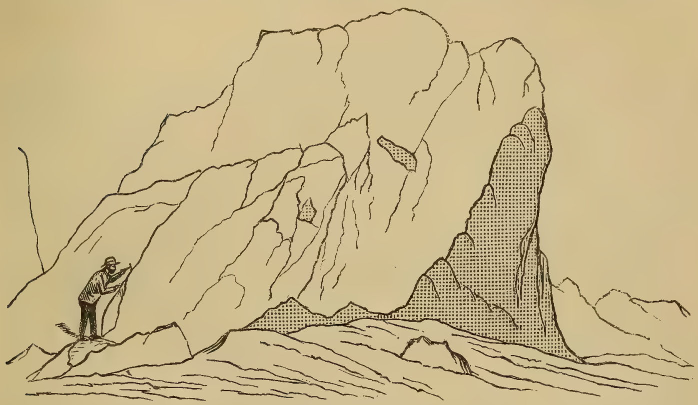
Fig. 2.—*Dioritic Rock and Serpentine, Lendalfoot.*



Explanation as in fig. 1.

latter in one place forces itself between two huge blocks in a wedge-like tongue; in another place a rhomboidal prominence, about 5 feet long, severs two "dioritic" blocks and supports a third (fig. 2); and in yet another case the serpentine still adheres to the other rock for a foot or two above the general level of the shore. Instances of this kind occur again and again on the shore. The annexed diagram (fig. 3) is a sketch of a huge block, not less than 50 feet long and

Fig. 3.—*Dioritic Rock and Serpentine, north of Lendalfoot.*



Explanation as in fig. 1.

20 feet high, on the shore about high-water mark and some 200 yards north of the hamlet. Here, as may be seen, the serpentine forms a sort of "skin" adherent to one side, and two or three fragments of it are still sticking in crevices in the "dioritic" rock. It would be simply repetition to describe other instances, which occur almost in dozens. The junction of the serpentine and "dioritic" rocks, when visible, is always perfectly clean, and conforms more or less to the irregularities of the latter, whose surface has a peculiar glazed aspect, and that sharp irregular jointing so characteristic of a rock affected by an intrusive igneous rock. The serpentine becomes rather more compact near the junction, thrusts itself in tongues into fissures, and remains yet sticking in crevices. The evidence of intrusion is even more clear than at the Lizard, and the two rocks adhere very imperfectly the one to the other, as is usually the case in Cornwall. I could not find a single instance of any thing like a passage from the one to the other; but the evidence of the intrusive character of the serpentine is, to my mind, so overwhelming that I cannot understand how it can ever have been doubted.

I now proceed to describe the principal varieties of the serpentine. About Lendalfoot it has a rather conchoidal fracture, with a very compact dark olive-green ground-mass containing rather minute and not very lustrous bronzitic crystals and thin veins of chrysotile. On placing a slide beneath the microscope, we see that the structure made so familiar by the Lizard specimens (vol. xxxiii. p. 916) is at once evident, though in this specimen the black iron peroxide is less markedly aggregated in the neighbourhood of the "strings" of doubly refracting serpentine, and the distinction between "string" and non-doubly refracting "mesh" is less conspicuous. Much of the iron is disseminated in extremely minute granules over the field, which, with crossed Nicols, shows us fibrous serpentine extending towards the centre of the mesh and sometimes occupying the whole. Where these strings are most clearly defined they exhibit a rough parallelism, and the fibrous structure is at right angles to them. The serpentine is irregularly banded with chrysotile. One vein shows unusually bright colours with crossed Nicols. There are two or three grains of a rich brown mineral, probably picotite. Here and there is a little of a fibrous, very strongly dichroic, green mineral, changing from light green to almost black. Altered bronzite is present in rather small grains, and a clear yellowish mineral with very minute belonites, about ·001 inch in length, crossing nearly at right angles, so as to form a sort of prismatic reticulation. A similar mineral is abundant in a serpentine from Menheniot (Cornwall), and in one from Santa Catarina, Elba, both of which rocks have some resemblance to this (though containing felspar). I am disposed, after examination of the latter and of bastite rock from the Hartz, to think this mineral either bastite or closely related to it*.

To the south of Carleton Foot we find serpentine of a red colour. This also thrusts itself into great masses of the "dioritic" series, which here is also often of a dull red colour. Bronzite crystals, and many thin irregular veins of chrysotile, occur in the serpentine, with occasionally rudely parallel layers and grey veins of a more decomposed serpentine. A great block on the shore, near the road-cutting, just south of the headland forming Carleton Port, shows an intrusive mass of serpentine and several small patches of the same adhering to the side. The block is finely and sharply jointed, and its surface has a glazed aspect. It is a dark-coloured rock, resembling a basalt. Red serpentine now becomes more frequent than the dark-green variety. The whole mass has a rather disturbed appearance: in one place there is a little serpentine breccia, probably a friction-breccia; in another place there are some curious dark veins in the red serpentine.

By the stone marking five miles from Ballantrae a compact dark serpentine again occurs, with roughly parallel steatitic bands, sometimes from 2 to 3 feet thick, and occasionally a greenish serpentine mottled with white steatite. Beyond this we come, a little to the south of Burnfoot, to a compact mottled dull-red variety of serpentine, with very small bronzitic crystals, beyond which we reach to the cliffs of porphyrite about Balcreuchan Port. These rocks, however (with a small intrusion of serpentine), will be noticed in due course.

The following is a description of the microscopic character of two varieties of the red serpentine from the above district:—

(1) Specimen from south of Burnfoot. In general structure this resembles the other, except that the "meshes" are often partly or

* Boricky (Basaltgest. Böhm. pl. 1) figures a rather similar arrangement of belonites in a magma basalt, and observes that they resemble the skeleton of an augite crystal.

wholly occupied by an imperfectly translucent ferruginous mineral of burnt-sienna colour, doubtless akin to hæmatite and the colouring-matter of the rock. There is some calcite in a crack traversing the slide, mixed possibly with a little minute dolomite; it also occurs associated with a microlithic "dust," replacing some (? pyroxenic) mineral. Bronzite is present, though in small grains, and much altered.

(2) Specimen collected from rocks a little to the south of Carleton-Port headland. This is a compact rock of an Indian-red colour, marbled or mottled with purplish or purplish grey, in which are rather rounded grains or "eyes" of a greenish mineral, apparently a decomposed bronzite. Under the microscope this rock is seen to be in general structure very similar to the last, but with the "strings" a little more definitely parallel; to these also the coarser part of the ferruginous constituent is rather more restricted, though an extremely minute dust is everywhere thinly disseminated in the serpentine. There is bronzite much altered, and a minute grain or two of picotite (?).

The dark serpentine from near the milestone named above is a dull purplish rock indistinctly marbled with dark greyish green, containing many glittering bronzitic crystals, with lustre but slightly metallic. Under the microscope it shows the usual characteristic ground-mass and a good many crystals of rather altered bronzite. The "steatitic" veins are opaque under the microscope, and are associated with a little bronzite and a fair quantity of a not very well-preserved mineral, which I believe to be augite.

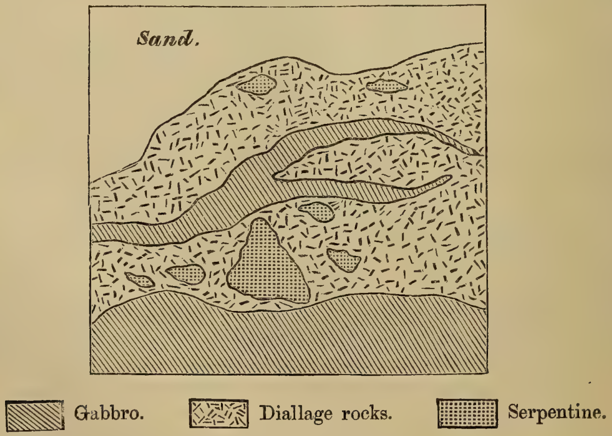
Returning to the hamlet of Lendalfoot, and following the shore northward to trace the serpentine, we find fresh evidence of its intrusive character; there are, however, some rocks, apparently intrusive in it, which we shall presently notice. North of the hamlet, the great blocks belonging to the "dioritic" series stand up in huge wall- or dyke-like masses. These are generally of a dark rock resembling basalt, occasionally porphyritic, with crystals of white felspar. Passing the block already noticed, near which are others almost as large, we observe everywhere the same evidence. Usually the serpentine may be seen *in situ* beneath these blocks; it thrusts a tongue or two into them and adheres to the side; the junction-surface has almost always a glazed appearance. Serpentine, commonly dark-coloured and with a clean subconchoidal fracture, seems generally to underlie the sand and boulders for about three quarters of a mile, when we come to some remarkable intrusive rocks, which we shall describe below.

A short distance beyond these the serpentine ends abruptly against a basalt dyke, on the other side of which is a dark schistose-looking tuff; and then comes the huge mass of porphyrite of Pinbain Hill.

The Gabbros.

These rocks, which have just been mentioned, are, as I fully believe, the hyperite and diallage rocks of Dr. J. Geikie, and, so far as I have seen, only occur on the shore in this one locality to the north of Lendalfoot. Rising conspicuously above the serpentine and the sand are two dykes of a hard whitish rock spotted with brown. A short examination shows this to be a gabbro of plagioclase and diallage, in which, as at the Lizard, the former mineral has been converted into a kind of saussurite. It always forms the major part, and sometimes almost the whole of the rock. As it resists the weather better than the diallage, the rock has often a curious "pock-marked" aspect. Close at hand is a most remarkable rock, best seen near the southern dyke of gabbro, though a little of it also occurs near the other. This rock consists almost wholly of coarsely crystallized submetallic diallage, the crystals being often two or three inches long*. It breaks into the serpentine in irregular branching veins, which die away in mere threads (remaining rather coarse to the last like the gabbro at the Lizard); in places it has almost shattered the serpentine, and includes fragments of it. Its weathered surface, as might be expected, is extremely rough, the diallage crystals projecting. The thicker parts of the mass form little skerries. Here the rock may be 4 or 5 feet thick, but generally it is in veins not more than a foot across. Careful examination left not the slightest doubt on my mind that this is a true intrusive rock, and has not been formed by segregation or otherwise. It seems at first sight connected with the adjacent gabbro dykes; but their obvious difference in mineral composition shows they cannot be contemporaneous. The junction is also sharp, showing no passage from the one to the other. A careful search settled the question of their relative ages. The annexed diagram (fig. 4)

Fig. 4.—*Gabbros and Serpentine.*



* Noticed by Dr. Geikie (*loc. cit.* p. 527) as "vein-like ramifications of diallage rock."

is a rough ground-plan of what was found on the north side of the gabbro dyke. Here the diallage rock contains fragments of serpentine from 2 or 3 inches to 12 or 15 inches in diameter, and is cut by a vein of gabbro corresponding with that in the main dyke. This vein, in greatest width, is about 4 inches; it runs roughly parallel with the main dyke, splits into two strings, and so dies away. Hence the gabbro is the latest of the three rocks. A little of the diallage rock is also exposed near the northern gabbro dyke, but its relations to the latter are less distinct. Here the gabbro cuts serpentine, which is intrusive into an altered "greywacke."

The following is Mr. Houghton's analysis of a specimen of the diallage in the above rock. It varies rather in amount of decomposition. An analysis of the least altered gave:—

	Dried at 100° C.
H_2O	9·10
SiO_2	47·22
Al_2O_3	2·76
FeO	10·02
CaO	6·51
MgO	25·59
	101·20

I have examined microscopically each of the above rocks. In the former the saussuritic mineral is partly translucent, but for the most part is rendered opaque by a fine earthy dust with a somewhat fibrous arrangement. With crossed Nicols the field is generally dark, but exhibits occasional specks and streaks of brighter colours and indistinct traces of aggregate polarization. In one or two parts, however, some very characteristic plagioclase felspar still remains (very transparent and free from all enclosures, except some minute dark acicular microliths), thus indicating the origin of the saussuritic constituent*.

The other constituent of the rock exists in three forms—(*a*) crystalline grains of diallage (and, in one or two cases, of normal augite) comparatively little altered; (*b*) uralite wholly or partly replacing diallage, green-coloured, strongly dichroic, exhibiting occasionally very characteristic hornblende cleavage; (*c*) a transparent nearly colourless and non-dichroic, rather fibrous mineral, which sometimes is associated with either of the above, sometimes occurs alone. Part of this exhibits brilliant colours with crossing Nicols; part changes from a light bluish white to a blue-black, like some fibrous serpentines: the former mineral is probably actinolite; the latter may be only a variety of serpentine. This rock then appears to have been originally a coarsely crystalline gabbro, which, perhaps, contained a little olivine.

The second rock is practically a mass of diallage crystals. Some of these are very fairly preserved, others are traversed by cracks with dusty borders showing incipient decomposition; while others

* *Cf.* Zirkel, Geol. Explor. of Fortieth Parallel, vol. vi. p. 107.

are green-coloured and dichroic, indicating a change towards uralite. Others, again, are full of microliths which are bright-coloured between crossed Nicols, while the main part of the crystal is dull or dark*. I cannot recognize any felspar in this slide, or any other mineral besides the above, except that probably one or two fibrous aggregates of serpentinous aspect are pseudomorphs after olivine†. The alteration indicated by the microscopic examination is confirmed by the analysis, which indicates a rather exceptional mineral.

A little beyond this spot the serpentine ends abruptly against a basalt dyke from 1 foot to 3 feet wide, which I think has come up along a line of fault. On the other side is a black tuff, rather schistose, containing many fragments of limestone and porphyrite, some of the latter being of considerable size, possibly even the ends of small *coulées*. If I am right in supposing Dr. J. Geikie to refer to this rock, and consider it as "resulting from the dissipating *in situ* of a limestone" (p. 528), I must express my surprise that any one accustomed to the study of volcanic rocks should not have at once recognized these as included fragments. The limestone itself has that peculiar, rather flinty, fracture so common when it has been indurated. Except that perhaps the matrix seems rather more earthy than usual, there is nothing exceptional about the tuff.

The Porphyrites.

Beyond this tuff we find the great mass of porphyrite which forms Pinbain Hill; this is marked on the map as altered Silurian. It is, however, a rock very similar in character to that at Balcreuchan Port; and as I examined the latter mass first and in more detail, I will select it for description, merely stating that whatever conclusion is true for the one is also true for the other. Both or neither are of igneous origin. Dr. J. Geikie regards both as simply instances of extreme metamorphism, the result of what we may call selective action. I am unable to agree with him, as the following description will show.

We descended from the high road to the water's edge at Balcreuchan Port, a romantic cove enclosed by precipitous cliffs. On the shore, rather on the southern side, is imperfectly exposed a little of a rather decomposed dark-coloured serpentine, apparently intrusive in a rock consisting of angular fragments of felstone in an earthy-looking decomposed ground-mass. Their condition and the nature of the ground—strewn here with boulders and débris—makes it difficult to form a decided opinion about this rock; but I have little doubt that it is really a coarse porphyrite tuff or volcanic agglomerate. Overlying this is a great mass of a hard reddish-coloured rock—here fairly compact—of which the whole cliff appears to be composed.

* Some of the least altered crystals in general appearance and in optical characters approach enstatite; I have not, however, been able to satisfy myself of the presence of that mineral, though these hardly appear to be normal diallage.

† I have in my collection a gabbro from Volpersdorf (Silesia) and a bronzite rock from the Kupferberg in Bavaria, which, macroscopically, seem to be as exclusively composed of the one mineral.

Towards the base the rock has a rather slaggy aspect, and is slightly vesicular. It generally exhibits an irregular jointed structure, the most developed planes being rudely parallel to the base; is occasionally slightly columnar and often rudely spheroidal, this structure being in one part very marked. Sometimes, also, curved subspheroidal joints may be seen. The spheroids are often traversed by radial cracks. Where parts of the shells have fallen away, and fragments have been left projecting from the rotten, dusty, or pasty material which has accumulated from decomposition, the rock has the look of a breccia. This, however, in the ordinary sense of of the word, I am convinced it is not. By clambering along the screes towards the south we found the rock become decidedly porphyritic, the crystals of the plagioclase felspar often being about $\frac{1}{3}$ inch long. Good specimens of the rock were difficult to obtain, as it was very tough and traversed by minute concealed joints. From the evidence in the field alone I should not hesitate to consider this a true igneous rock, and probably a lava-flow. This view is fully confirmed by microscopic examination. The following is the description of a slide cut from the more porphyritic part:—

The slide exhibits a very minutely granular brown base, almost homogeneous and nearly opaque, probably consisting of a decomposed glassy felspathic matter stained with iron peroxide. This base is crowded with felspar microliths, together with rather irregular spots of viridite; and in it are scattered some small, but distinct, grains of magnetite and some larger felspar crystals. The felspar microliths are commonly about 0·005 inch, or a little less, in length. The majority are certainly plagioclase, but there are some which may be orthoclase. The viridite is very clear, only now and then containing a little dark dust, and the mineral which it has replaced crystallized subsequently to the felspar. The larger crystals of felspar are a good deal decomposed, exhibiting spots of viridite and other endomorphs, many probably of secondary formation. The felspar, in many cases at least, has been plagioclase. The rock, then, may be safely named porphyrite.

The above description will in most respects serve also for the northern rock. I had no doubt when on the ground that it too was a lava-flow; and the microscopic structure of a porphyritic variety is as follows:—

The specimen is of a darker and greener colour than the Balcreuchan rock, and exhibits crystals of whitish plagioclase and some dark irregular spots. Under the microscope the structure is seen to differ in several respects from the above rock. There appears here to have been but little base or cryptocrystalline ground-mass. The slide mainly consists of plagioclase felspar in small crystals, augite, much being still unaltered, and viridite, together with some iron peroxide and a granular brown mineral. In this, as a ground-mass, are scattered larger felspar crystals. This mineral is much altered, earthy in aspect; but enough remains to show that at any rate the majority of the crystals, small and large, are plagioclase. The augite is very little affected, is clear and almost colourless, and shows bright tints with crossed prisms. The viridite has a finely fibrous structure, and sometimes a banded arrangement. It is fairly dichroic, exhibits aggregate polarization, and shows low tints, varying from pale greenish blue to dull brown, as the polarizer is rotated. It is doubtless allied to delessite*. I have seen it occasionally in basalts, *e. g.*, in one from Hawkscrag, Fifeshire coast, where it replaces augite. Here it is more doubtful what the original mineral has been, since the augite which remains seems so well preserved†. Either it has been olivine (but I hardly think so) or a different variety of augite. A few globulitic grains of granular structure and semiopaque brown tint are scattered in it. From the microscopic examination I conclude that this rock is a rather more basic porphyrite than the other one.

It too appears to rest on a tuff (already described), and I had suspicions that the latter was unconformable with the supposed Silurian rocks, though I could not obtain evidence on this point which was quite conclusive. The porphyrite extends along the coast for nearly a mile, and is here and there cut by a basalt dyke. Seeing that the older rocks of the district appear to be inclined at a high angle, we might well be surprised, if it were one of that series, at the great thickness and homogeneous character of this rock. To my mind the extent of ground covered by it is strongly in favour of the idea of this porphyrite being part of a lava-stream that has passed over the denuded edges of older beds.

Later Basaltic Dykes.

There are occasional rather narrow dykes of basalt cutting the above-described porphyrites, as well as that mentioned above (p. 780.) At these, as a rule, I only glanced, as there was nothing in them, so far as I saw, different from the dykes so abundant in Western Scotland. I took, however, a specimen from one, that marked on the map just to the north of Balcreuchan Port, which I have since examined. It is a compact green-black basalt with many rounded white spots, like minute amygdaloids, showing on fractured surfaces a rather fibrous structure and slightly silky lustre. Under the microscope both the plagioclase and augite of the rock are seen to be much altered. The white spots show an isotropic mineral which is transparent, except where somewhat clouded with fine dust, and has an imperfect cleavage. It may be analcime. In it, generally about the edges, are a great number of minute rosettes of a greenish mineral, fairly dichroic, and showing a pale golden colour and an aggregate polarization. Part of one of these amygdaloids is almost wholly occupied by a different mineral. It crystallizes in radiating needles, belonging apparently to the orthorhombic system, with a fairly marked basal cleavage. With crossed Nicols it shows rather bright colours. It may possibly be stilbite.

Near Lendalfoot hamlet, however, are some dykes which appear to

* Zirkel, Geol. Explor. &c. p. 13.

† The augite and viridite are sometimes contiguous with a perfectly sharp line of demarcation.

be intrusive in the serpentine. They occur near the side of a burn, which runs into the sea rather less than 100 yards north of the toll-gate. I observed two to south and one to north. They are veins rather than dykes. In the thicker parts they resemble dolerites, mottled dull white and dark grey (something like a fine variety of the Corstorphine rock), and they appear to pass (débris and weed made it a little difficult to trace the connexion perfectly) into thin veins (less than 1 foot thick) of a compact pinkish grey rock with dull green spots.

I have examined one specimen of the coarser rock from the north, and four of various degrees of coarseness from the south of the burn, The result of this examination confirms my view of the igneous character of these rocks. The coarser varieties consist mainly of felspar (or rather of what was once felspar, probably plagioclase, but is now an aggregate of earthy dust and bright-coloured irregular microliths), of well-preserved augite, of a serpentinous mineral, and of decomposed ilmenite. The finer variety is so completely decomposed as to show little of its original constitution. The slide is rendered almost opaque by a brown dust, with occasional clear interspaces, sometimes evidently pseudomorphs after a crystal, filled with a serpentinous mineral. There is, however, no reason why these may not once have been basalts, and more compact conditions of the other rock; for the original structure is quite as much obliterated in a specimen of "white trap" from the coast near St. Monace (Fife) in my collection. We have here, then, some doleritic dykes intrusive in the serpentine.

On ascertaining that some of the rocks included in the serpentine in this neighbourhood were also doleritic, I was naturally struck by the singularity of the occurrence of two dolerites in the same locality with a serpentine of intermediate age; and I have carefully considered the point, as to whether the former set may not also have been intrusive in the serpentine. Though I cannot say that in one or two cases out of so many the relative ages of the supposed "diorites" and the serpentine may not have been unnoticed by me (as I was mainly occupied in investigating the question of their asserted passage one into another), still I do not think it probable; and I feel certain that, as a whole, Dr. Geikie's "dioritic series" is of earlier date than the serpentine, and that some at least of my specimens came from rocks belonging to that series.

Conclusion.

It results, then, that after consideration of both the appearance in the field and the results of microscopic examination, I see no escape from the following conclusions:—

1. That the serpentine of this district is intrusive, and, like so many others, is an altered olivine rock.

2. That there is no hypersthene rock, but gabbros of two ages, both of igneous origin, the first extraordinarily rich in diallage, so

that it can hardly be called a gabbro, the second much resembling the later gabbro of the Lizard, Cornwall*.

3. That the porphyrites of Balcreuchan and Pinbain Hill are true igneous rocks, and very probably remnants of lava-flows associated with tuffs or agglomerates.

4. That several of the rocks into which the serpentine is intrusive are also igneous, and are augitic, not hornblendic.

5. That there are some doleritic and basaltic dykes of later date than all the above.

6. That Dr. Geikie's conclusions as to the non-igneous character of the rocks of this district are, so far as regards all the above named, unsupported by either stratigraphical, petrological, or lithological evidence, the proofs of intrusion being remarkably clear and indubitable, so that this district must be removed from the list of those which have been supposed to favour the theory of the production of pseudo-igneous from stratified rocks by selective metamorphism.

The fact of intrusive serpentine, of gabbros of two ages, and later basalt dykes being here associated together, as in the vicinity of Coverack Cove, Cornwall, is a little remarkable.

As for the date of the above rocks, these last-named basalts are probably Miocene; the porphyrites (with which I connect those of Knockdolian Hill) are probably outliers of one or more great lava sheets, and no doubt, like others in that part of Scotland, of Old Red Sandstone (probably Middle) age.

The group of rocks into which the serpentine is intruded, speaking in general terms, is described by Sir R. Murchison as of "Lower Silurian age, Bala, or even Lower Llandovery" ('Siluria,' p. 155†). Hence the serpentine is later than this epoch, and, as I have shown, almost certainly later than the porphyrite tuffs. The serpentine dyke described by Sir C. Lyell‡ is intrusive in the Lower Old Red Sandstone of Forfar, and so may possibly form one of a series with those described above. The diallage rock and gabbro north of Lendalfoot must be yet more recent than the serpentine, still all are probably Palæozoic.

Discussion.

Mr. Warington W. Smyth remarked on the extraordinary resemblance of the rocks of Ayrshire to those of the Lizard district, and pointed out that this confirmed the views insisted upon on chemical grounds by the late Mr. David Forbes.

* See Quart. Journ. Geol. Soc. vol. xxxiii. p. 895 *et seq.*

† See also Quart. Journ. Geol. Soc. vol. vii. p. 137.

‡ Edin. Journ. Sc. vol. iii. p. 112. By the kindness of Professor Judd I have had an opportunity of examining this serpentine, and have no doubt it is an altered olivine-enstatite rock. I have also examined, by favour of Mr. Grieve (Burntisland) and Mr. Hawkins Johnson, F.G.S., some serpentines from Portsoy (Banff), and find them to be generally similar to those which I have been describing in this paper, except that I have often not been able to establish the presence of enstatite, though in some a rather minute pyroxenic constituent is abundant.

Prof. SEELEY thought that many rocks, when examined over a broad area, might be regarded as of metamorphic origin, and yet might sometimes be intrusive, and seem to be igneous in small exposures, without ever having been connected with flows of lava. He thought that Mr. Mallet's theory of vulcanicity supported the adoption of this view.

Mr. HUDLESTON objected that Prof. Seeley had not defined the terms volcanic and metamorphic.

Prof. DUNCAN pointed out that originally the position maintained by Dr. Geikie was that grauwacke had been altered *in situ* into serpentine, and this Prof. Bonney had shown to be altogether inadmissible.

Prof. JUDD insisted on the importance of not confusing the definitions of igneous and metamorphic rocks. He said that the serpentine dykes of Forfarshire were almost certainly of Carboniferous age.

Rev. E. HILL, from personal examination of the district, confirmed Prof. Bonney's views as to the intrusive character of the rocks in question.

Prof. BONNEY, in reply, said that he thought the intrusive rocks of Ayrshire were very probably of Carboniferous age. He asserted that there was nothing like a transition of the serpentine into the rocks into which it is intruded. He did not accept Mr. Mallet's views as to the formation of certain rocks by crushing action.

45. Remarks *on* Saurocephalus, *and on the* Species *which have been referred to that* Genus. By E. T. Newton, Esq., F.G.S., H.M. Geological Survey. (Read June 20, 1878.)

In the year 1824 Dr. Harlan described a portion of a fossil jaw which had been obtained in 1804, during an expedition up the Missouri, from what were believed to be Secondary rocks (Journ. Acad. Nat. Sci. Philad. 1830, vol. iii. p. 331). Dr. Harlan thought this specimen showed reptilian affinities, and compared it with certain species of *Ichthyosaurus*; but, believing it to be generically distinct, he named it *Saurocephalus lanciformis*. Prof. Owen subsequently showed ('Odontography,' p. 130, pl. 55) that this specimen was to be referred to the group of Fishes.

There has been so much misunderstanding about the genus *Saurocephalus*, to which certain specimens in this country have been erroneously referred, that it has been thought desirable to bring together all the known facts, in order, if possible, to correct the synonymy of the species.

Dr. Harlan (*l. c.* p. 335), after giving the measurements of the bone above mentioned (now known to be a maxilla), says:—"There are eighteen teeth in different states of preservation; the longest are seven tenths of an inch, two tenths only projecting above the bone, the projecting part enamelled, smooth, and shining, lanciform; the edges are very sharp. . . . The bodies of the teeth are all hollow, and are firmly fixed in a longitudinal groove, there being no distinct separate alveolæ. The bodies of the teeth are in *close contact throughout*. . . . The body of the bone is not perforated by a canal for the inferior maxillary nerve, in place of which is observed a groove running the whole length of the dental bone, immediately beneath the alveolar portion, on the mesial aspect of the bone; the bottom of this groove is perforated with foramina for the distribution of the nerves and blood-vessels, equal in number to the teeth (*i. e.* 18)."

As regards the teeth being in grooves, Dr. Harlan seems to have been mistaken. Dr. Hays in 1830 (Trans. Am. Phil. Soc. vol. iii. p. 471), when describing his *Saurodon Leanus*, examined the original specimen of *Saurocephalus*, and found that the teeth were really lodged in distinct alveoli; he gives a figure of a portion of the jaw from which the outer lamina has been removed, so as to show the alveoli and the form of the teeth. The close affinity of *Saurocephalus* and *Saurodon* was recognized by Dr. Hays, and he proposed to place them both in his genus *Saurodon*, which he thus characterized:—"Teeth of lower jaw closing within those of the upper like incisors; a regular series of foramina along the inner aspect of the jaws near their alveolar margins, for the passage of nerves and blood-vessels to the teeth."

Prof. Agassiz in the year 1843 (Poiss. Foss. tom. v. p. 101) referred certain large flattened teeth from the White Chalk of Sussex, which had been figured by Dr. Mantell in his 'Geology of Sussex' (pl. xxxiii. figs. 7 & 9), to Harlan's *Saurocephalus lanciformis*, but does not state why he so refers them. A comparison of Agassiz's figures (pl. xxv^{c}. f. 21–29) with those given by Harlan (*l. c.* pl. xii.) will, I think, be sufficient to throw doubt upon their belonging to the same species. Prof. Agassiz doubtless had good reasons for referring these teeth to Harlan's genus and species, but does not mention them in the text. If Agassiz's figures be compared with figure 7 of Harlan's plate, the close resemblance between them will be at once seen; and when first referring to this plate I was struck with the similarity, and thought that the well-known teeth from the English Chalk had been correctly referred to Harlan's species; but upon turning to the explanation of the plate I found that this identical tooth (fig. 7) was circular in section, and, moreover, that it belonged to an *Ichthyosaurus* which was described in another paper, but the figures had been mixed on this plate. Is it possible that, in some way, this unfortunate intermingling of the figures was the cause of a mistake?

Dixon, in his 'Fossils of Sussex' (1850), figured a lower jaw (pl. xxxi. f. 12) bearing large flattened teeth, resembling those figured by Agassiz. This jaw he also refers to *Saurocephalus lanciformis*. In a note on page 375 he says that "Sir P. Egerton has obtained a specimen of *Saurocephalus lanciformis* showing that the premaxillary bones were prolonged into a rostrum, as in the Xiphioids (tab. xxxii*. fig. 1)".

In the year 1856 Dr. Leidy carefully redescribed the original specimen of *Saurocephalus lanciformis* (Trans. Am. Phil. Soc. 1860, vol. xi. p. 91, pl. vi.), and pointed out, among other interesting characters of the specimen, that the teeth "have the same mode of insertion and order of succession as in the existing *Sphyræna*," and that their crowns have the "trenchant borders finely denticulate." Dr. Leidy considers that the isolated teeth figured by Agassiz (*l. c.* pl. xxv^{c}. f. 21–29), and the jaws and teeth figured by Dixon (*l. c.* pl. xxx. f. 21, pl. xxxi. f. 12, pl. xxxiv. f. 11), have been erroneously referred to *Saurocephalus lanciformis*, and therefore establishes a new genus and species for their reception, which he names *Protosphyræna ferox*. The rostrum figured by Dixon (pl. xxxii*. f. 1) he did not think belonged to the same fish, and consequently gave it another name, *Xiphias Dixoni*.

The specimens lately obtained in America by Prof. Cope show that Sir Philip Egerton was correct, and that this rostrum and lower jaw do belong to the same kind of fish.

A corrected list of the fishes which have been attributed to *Saurocephalus* is given at the end of Dr. Leidy's paper. This list, with some modifications, is included in the one given below (p. 794).

More recently specimens of jaws with teeth, resembling those represented by Dixon, have been discovered in the Cretaceous rocks of North America, and described by Cope (Geol. Surv. Terr. 1875, vol. ii. Cret. Vert. pp. 217, 275), who has established a new genus for their reception, *Erisichthe*, believing that the differences between them and *Saurocephalus* were of even more than generic importance. The similarity between the portion of lower jaw figured by Cope (*l. c.* pl. xlviii. f. 6) and that given by Dixon (pl. xxxi. f. 12) is such that no one would have much doubt of their generic relationship. Some specimens, obtained during 1877 from the Niobrara Cretaceous of Kansas, have enabled Prof. Cope to make still further additions to our knowledge of these peculiar fishes (Bulletin 6, Geol. Surv. Terr. 1877, p. 821); and he describes three new species, which he distinguishes by the form of the rostrum, and then concludes by saying, "A fourth species has been found in England, and figured by Dixon in the 'Geology of Sussex.' The portions represented in this work [Dixon] are the mandibles, which resemble those of the *E. nitida*, and which were supposed at that time to belong to a species of *Saurocephalus*. A muzzle, perhaps of the same species, was regarded as a Sword-fish, which was called *Xiphias Dixoni* by Agassiz. It should be now termed *Erisichthe Dixoni*." Prof. Cope does not appear to have known that Dr. Leidy had already named the English specimen *Protosphyræna ferox*, by whom also the name of *Xiphias Dixoni* was proposed for the rostrum figured by Dixon. Agassiz was not the author of this name.

A due consideration of the facts of the case show conclusively, as it seems to me, 1st, that the specimens figured by Messrs. Agassiz and Dixon, and referred by them to the *Saurocephalus lanciformis* of Harlan, do not belong to that genus and species, and this species will have to be expunged from our lists of British fossils; 2nd, that these specimens do agree generically with those described and figured by Prof. Cope.

Dr. Leidy in 1856 proposed, as already mentioned, the generic name of *Protosphyræna* for these British specimens; and this name therefore must be adopted, and not that of *Erisichthe*, which was given by Prof. Cope in 1872 to the American specimens.

The most important characters of the genus *Protosphyræna*, as we now know them, are the elongation of the ethmoidal region into a rostrum resembling that of the sword-fish, and the peculiar form of the mandible (*vide* Dixon, Foss. Suss.). Both the upper and lower jaws have large compressed teeth, lodged in distinct alveoli, besides other smaller teeth. The following description of the *Protosphyræna* (*Erisichthe*) *nitida*, Cope, recently obtained from the Niobrara Cretaceous of Kansas, will give the best idea of the structure of the head of these fishes (Cope, Bull. Geol. Surv. Terr. 1877, vol. iii. n. 4, p. 821):—"From this and other specimens I discover that the anterior portion of the skull, probably the ethmoid bone, is produced into a long beak, in general form similar to the sword-like snout of the Sword-fishes of modern seas. . . . A remarkable feature of the genus is displayed in the mandibles. Each of these is compound in the region usually composed of the simple dentary bone. It there consists of three parallel elements, an internal and an external embracing a median element. The inner bears a band of teeth *en brosse* on its inner and superior aspect, and the external a few teeth of similar character on its superior edge. The large lancet-shaped teeth are borne by the middle element, excepting some of the largest near the symphysis. Two of these on the inner side of the ramus originate in the internal bone. The maxillary bone forms the greater part of the arcade of the mouth, and has no superior articulation with the facial part of the skull. It is attached by a simple sutural articulation with the premaxillary, so as to permit of some lateral motion. The premaxillary also has no superior condyle articulating with the cranium, but the entire length of its superior margin is applied in a groove of the ethmoid bone, so as to be immovable. Anterior to the premaxillary bones, on the inferior aspect of the ? ethmoid, is situated a pair of large, compressed, double-edged teeth, whose alveoli are close together."

The different forms of the rostra have been taken by Cope as specific characters. In *P. nitida* "this weapon is distinguished by the flat superior surface of its distal half. The section in this region is semicircular." *P. penetrans* "has a snout of uniformly oval section at all points." In *P. ziphioides* "the form of the muzzle is quite peculiar. Its shaft is depressed, with a strongly convex inferior surface and a slightly convex superior surface, the two separated by an obtuse angular border," &c.

The rostrum figured by Dixon is nearly circular in section throughout, and therefore differs from all the above American species. This difference was observed by Cope, who proposed that this specimen and the mandible represented in the same work should be known as *Erisichthe Dixoni*; this name, however, must give place to the older one of *Protosphyræna ferox*, given by Leidy to the mandible in 1856.

Although numerous specimens of teeth, parts of jaws, and rostra have been obtained from British Cretaceous strata, yet all the fragments of rostra with which I am acquainted resemble that figured by Dixon in being nearly circular in section; the other portions found are not sufficient to afford grounds for specific distinction. At present, therefore, we are only able to record one species of this genus as occurring in Britain, viz. *Protosphyræna ferox*.

Sir Philip Egerton has kindly called my attention to the following foreign species which have been referred to the genus *Saurocephalus*, viz. *S. albensis*, Pictet & Campiche; *S. dispar*, Hébert; *S. inæqualis*, Münster; *S. inflexus*, Pictet & Campiche; and *S. substriatus*, Münster. These species have all been founded on isolated teeth, and it seems to me that there must be considerable doubt as to their generic and specific affinities.

Saurodon Leanus was first described by Dr. Hays in 1829 (Trans. Am. Phil. Soc. 1830, vol. iii. p. 471). The specimen was obtained from the Greensand near Moorestown, New Jersey. It includes the upper and lower jaws of both sides. The author recognized the close relation existing between this specimen and the *Saurocephalus lanciformis* of Harlan, and in his description mentions, among other points of structure, the following:—" The dentary has a single row of alveoli, and just below the border there is a row of foramina, one to each alveolus. The teeth of the lower jaw close within those of the upper. Intermaxillary very distinct, and united by squamous suture with the maxilla. The alveoli show that the teeth projected. The maxilla has distinct alveoli for teeth, and just within the border on the inner surface there is a regular series of foramina similar to those of the dentary. The exterior of this bone, where not broken, presents a shagreened appearance. The teeth in both jaws are similar, and placed close together in a single row; those of the lower jaw, however, are rather more compressed than those of the upper, and the anterior teeth of the lower jaw are smaller than the posterior ones. The crowns are enamelled, smooth, lanciform, slightly incurved, and the hinder ones of the lower jaw slightly curved forwards. Their roots are hollow, and slightly grooved on their inner and outer faces. There appear to have been 9 or 10 teeth in the intermaxillary, and about 30 in the maxilla; the number in the dentary not known." Dr. Leidy says there were about 42 teeth in the dentary of this specimen.

Dr. Hays proposed to place this species in the same genus with *S. lanciformis*, with the generic name of *Saurodon*, and the distinctive characters of the genus have been given above (p. 786). The two species are thus distinguished:—

"1. *S. lanciformis*. A groove along the inner surface of the dental bone for the accommodation of the inferior maxillary nerve; teeth very obtusely lanciform."

"2. *S. Leanus*. Teeth acutely lanciform, much smaller than in preceding species, slightly curved."

Dr. Harlan in 1834 (Edin. New Phil. Journ. vol. xviii. p. 28) pointed out that Dr. Hays was altogether wrong in establishing a new genus (*Saurodon*) for those two species, when he (Dr. Harlan) had already in 1824 given the name of *Saurocephalus*. The latter name no doubt has the priority, and must therefore be adopted.

Prof. Agassiz, in his 'Poissons Fossiles' (vol. v. p. 102), refers certain peculiar teeth from the Chalk of Lewes to the *Saurodon Leanus* of Hays, but unfortunately does not give his reason for so referring them. In his description he says, "in place of being regularly conical, as in *Saurocephalus*, they are curved backward, and their points are cut obliquely with an inflated margin (*un rebord renflé*). The surface is finely striated from the base almost to the summit. At the base of the tooth is a pronounced annular enlargement, under which one can see the root, which is reticulated. . . . One of these teeth is represented enlarged in fig. 31. The root appears to be united with the bone of the jaw, but it is not sufficiently preserved in our specimen to allow its intimate structure to be made out."

Why this peculiarly *barbed* tooth should have been referred to the *Saurodon Leanus*, in which the crowns of the teeth are simply flattened and slightly incurved, I cannot clearly understand; for the forms of the two teeth seem to me widely different. Compare Poiss. Foss. t. v. pl. xxv^{c}. f. 30, 31, with Trans. Am. Phil. Soc. 1830, vol. iii. pl. xvi. f. 7–9.

In Dixon's 'Fossils of Sussex' a specimen is figured (pl. xxxii*, fig. 10) which bears teeth similar to those just mentioned as figured by Agassiz, and, like them, is referred to *Saurodon Leanus*. This specimen is described in the text as follows:—"The specimen figured is of great interest; it shows the lower jaws united at the symphysis, and a portion of the right palatine bone in its natural position. . . . The barbed teeth described by M. Agassiz are those on the palatine bone, their edges are finely serrated; the teeth of the lower jaw are of an entirely different form, the base is broad and fluted, the blade compressed and recurved, with a sharp, finely serrated edge; they are separated by wide intervals, which are filled by innumerable small pointed teeth."

The differences between this specimen and the type of *Saurodon Leanus*, Hays, are so obvious that surely they only need to be pointed out in order to be generally acknowledged. Notwithstanding this, and although Dr. Leidy first called attention to these differences in the year 1856 (Trans. Am. Phil. Soc. 1860, xi. p. 94), up to the present time the name of *Saurodon Leanus* has been retained in our lists of British fossil fishes. Dr. Leidy, towards the end of his paper, says:—"To *Saurodon Leanus*, Hays, Agassiz has erroneously referred the fragment of a palate-bone with teeth (Poiss. Foss. v. p. 102, pl. xxv^{c}. figs. 30, 31) of another large Sphyrænoid fish from the Chalk of Lewes, England. Though the true *Saurocephalus* may have had semibarbed teeth to the palate-bone, like those just referred to in the fragment described by Agassiz, yet this could not fairly be inferred from the condition of the living *Sphyræna*."

Dixon has noticed and represented (Geol. Sussex, p. 373, pl. xxx. figs. 28, 29, pl. xxxii*. fig. 10) several large, isolated, semibarbed teeth, and a lower jaw and palate-bone with teeth, which, following Agassiz, have been referred to *Saurodon Leanus*, Hays, "to which they certainly cannot belong." From the above quotation it will be seen that Leidy is firmly convinced of the generic distinctness of the true *Saurodon Leanus* and the specimens figured by Agassiz and Dixon and called by the same name.

In order to be as certain as possible about this matter, I have compared the original specimen figured by Agassiz and Dixon, and also another in the Museum of Practical Geology which has similarly barbed teeth, with the descriptions and figures given by Hays and Leidy, and I find that there are even greater differences than have hitherto been pointed out. Agassiz's type is merely a fragment of bone with two or three barbed teeth; both the other specimens have part of the lower and upper jaws; but in neither of them does there appear to be any trace of the maxilla or premaxilla. The lower jaw is shallow in proportion to its length, and has as great an extent horizontally as vertically; in *S. Leanus*, Hays, on the contrary, the lower jaw has a greater vertical than horizontal extent. In the British specimens the large teeth in the lower jaw have compressed crowns, curved backwards and striated; but these have *no roots lodged in sockets*, the expanded base resting upon, and being firmly ankylosed to, the jaw. The form of the mandible might have led one to infer that there were no roots; but a fracture through the jaw in the region of one of the teeth places this beyond doubt, showing, as it does, that the teeth are hollow, without fangs, and merely ankylosed to the surface of the bone in a manner similar to that which obtains in the fixed teeth of the pike. The points of some of the teeth are seen to be furnished with minute caps of enamelled substance. In Mr. Willett's specimen, figured by Dixon (pl. xxxii*. fig. 10), the bone of the roof of the mouth bears the barbed teeth, and has been regarded as a palatine bone; but I think there is now evidence of its being the pterygoid, for its anterior part seems to have been attached to another bone; and furthermore, in a specimen in the Jermyn-Street Museum, there are two bones in this region—an anterior one, which I regard as the palatine, and a posterior one, corresponding with that preserved in Mr. Willett's specimen, which is probably the pterygoid. Both these bones carry barbed teeth, which are ankylosed in a similar manner to those of the lower jaw. In some of these barbed teeth it may be noticed that the sharp cutting-edge of the front convex border only extends from the apex about halfway down the tooth.

It is very unlikely that the *S. Leanus* of Hays ever possessed palatine teeth; but, however that may be, the mode of implantation of its teeth is totally different from what occurs in the British specimens in question; and the necessity of placing the latter in a separate genus, will, I think, be obvious to all who carefully consider the structural differences which they present. Dr. Leidy had already seen the necessity for this change in 1856, and gave the name of *Cimolichthys levesiensis* to these British specimens. The name of *Saurodon Leanus*, therefore, must now be erased from our lists of British fossils.

In the year 1845 M. Reuss (Böhm. Kreide, p. 8) named certain fragmentary barbed teeth *Spinax marginatum*. These specimens were referred with considerable doubt by M. Hébert (1854, Mém. Soc. Géol. France, ser. 2, vol. v. p. 350), together with others which he describes, to the genus *Anenchelum* of Blainville (1818, 'Sur les Ichthyolites,' pp. 9, 87), retaining for them the specific name of *marginatum*. It is probable that these teeth are generically identical with the English ones hitherto referred to the *S. Leanus* of Hays; but I do not think we should be at all justified now in placing them in the genus *Anenchelum*, concerning which so little is known. It may be that Reuss's specimens will eventually prove to be of the same species as the English ones; but it seems to me that it would not be right to adopt the name of *Cimolichthys marginatus* for the English specimens without stronger evidence than is afforded by these isolated teeth.

Saurocephalus striatus was founded by Agassiz (Poiss. Foss. vol. v. p. 102) upon a fragment of a jaw in Dr. Mantell's collection containing three teeth, resembling in form those of the so-called *S. lanciformis*, but much smaller and striated. No mention is made of any series of foramina along the inner aspect of the jaw, which is one of the most marked characters given by Drs. Harlan and Hays for this genus. I have examined the type specimen, now in the British Museum, upon which Agassiz founded this species, and also others in the Museum of Practical Geology, and can find no trace of the characteristic foramina: the specimens, it it true, are mere fragments, with one side in the matrix, and therefore one cannot speak with certainty; but a close examination reveals another most unexpected fact, which is, that the teeth are *not implanted in sockets*, as in both upper and lower jaws of *Saurocephalus*, but are merely ankylosed to the edge of the jaw, having no true fangs. This difference of structure is one of such importance that it cannot but be regarded as generically distinctive; and this species must therefore be removed from the genus *Saurocephalus*. Dr. Leidy, not knowing the mode in which the teeth were fixed to the jaw, referred this species to his genus *Protosphyræna*: but it will be obvious from what has been said above that it cannot be placed in that genus. The only specimens which can be referred to this species are such small fragments that it seems to me impossible to speak with any thing like certainty of their generic affinities; but their mode of dentition, it will be noticed, agrees with that observed in *Cimolichthys levesiensis*—that is, the teeth are ankylosed to the surface of the jaw and are not implanted in sockets; and I should propose, therefore, provisionally to call this species *Cimolichthys*? *striatus*, although it seems very probable that it will eventually prove to belong to a distinct genus.

There is considerable doubt in my mind as to whether the specimen figured by Dixon as *S. striatus* (pl. xxxv. fig. 5) really belongs to this species. The teeth certainly appear to be without fangs, and are ankylosed to the jaw in the same manner as they are in *C. striatus*; but the teeth are not so much flattened, neither are they set close together in a regular series, but are placed at intervals; moreover they are of very different sizes, some being very small. Judging from specimens in the British Museum, it seems likely that the specimen figured by Agassiz is a portion of a maxilla, and may well have belonged to a fish with a lower jaw such as that figured by Dixon (pl. xxxv. fig. 5). The form of this jaw, however, and the mode of its dentition are similar to what are found in *Cimolichthys levesiensis*, Leidy, although the forms of the teeth are different; and, it will be remembered, the form of the maxilla of the latter species is not known. I would suggest, therefore, that until we have better evidence of the form and structure of Agassiz's *C. striatus*, the jaw figured by Dixon be regarded as the same species, and that both, for the present, be placed in the genus *Cimolichthys*.

List of Genera and Species which have been referred to Saurocephalus, *&c.*

Saurocephalus lanciformis, Harlan. (America.)

Saurocephalus lanciformis, Harlan, 1830, Journ. Ac. Nat. Sci. Philad. vol. iii. p. 331, pl. xii. f. 1–5.

Saurodon lanciformis, Hays, 1830, Trans. Am. Phil. Soc. vol. iii. p. 476, pl. xvi. fig. 11.

Saurocephalus lanciformis, Harlan, 1834, Trans. Geol. Soc. Penn. vol. i. p. 87; Harlan, 1835, Med. & Phys. Res. p. 362, figs. 1–5; Owen, 1843, 'Odontography,' p. 130, pl. lv.; Leidy, 1856, Trans. Am. Phil. Soc. 1860, vol. ii. p. 91, pl. vi. figs. 8–11; Cope, 1875, Geol. Surv. Terr. vol. ii. Cret. Vert. pp. 216, 275.

Saurocephalus Leanus, Hays. (America.)

Saurodon Leanus, Hays, 1830, Trans. Am. Phil. Soc. vol. iii. p. 471, pl. xvi. f. 1–10.

Saurocephalus Leanus, Harlan, 1834, Trans. Geol. Soc. Penn. vol. i. p. 87; Edin. New Phil. Journ. vol. xviii. p. 28; Leidy, 1856, Trans. Am. Phil. Soc. 1860, vol. xi. p. 91, pl. vi. f. 12–15.

Saurodon Leanus, Cope, 1875, Geol. Surv. Terr. vol. ii. Cret. Vert. p. 275.

Saurocephalus arapahovius, Cope. (America.)

Saurocephalus arapahovius, Cope, 1872, Proceed. Am. Phil. Soc. vol. xii. p. 343; Cope, 1875, Geol. Surv. Terr. vol. ii. Cret. Vert. pp. 216, 275, pl. xlix. f. 5.

Protosphyræna ferox, Leidy. (England.)

Unknown fish, Mantell, 1822, 'Geology of Sussex,' p. 227, pl. xxxiii. f. 7–9.

Saurocephalus lanciformis, Agassiz, 1843, Poiss. Foss. vol. v. p. 102, pl. xxv[c]. f. 21–29; Dixon, 1850, Foss. Suss. p. 374, pl. xxx. f. 21, xxxi. f. 12, xxxii*. f. 1, xxxiv. f. 11.

Protosphyræna ferox, Leidy, 1856, Trans. Am. Phil. Soc. 1860, vol. xi. p. 91.

Xiphias Dixoni, Leidy, 1856, ibid. p. 91.

Erisichthe Dixoni, Cope, 1877, Bull. Geol. Surv. Terr. vol. iii. p. 821.

Protosphyræna angulata, Cope. (America.)

Portheus angulatus, Cope, 1872, Proc. Am. Phil. Soc. vol. xii. p. 337.

Erisichthe angulatus, Cope, 1875, Geol. Surv. Terr. vol. ii. Cret. Vert. pp. 217, 275; 1877, Bull. Geol. Surv. Terr. vol. iii. p. 821.

Protosphyræna nitida, Cope. (America.)

Erisichthe nitida, Cope, 1872, Proc. Acad. Philad. p. 280; 1875, Geol. Surv. Terr. vol. ii. Cret. Vert. pp. 217, 275, pl. xlviii. f. 3–8; 1877, Bull. Geol. Surv. Terr. vol. iii. p. 821.

PROTOSPHYRÆNA PENETRANS, Cope. (America.)

Erisichthe penetrans, Cope, 1877, Bull. Geol. Surv. Terr. vol. iii. p. 821.

PROTOSPHYRÆNA ZIPHIOIDES, Cope. (America.)

Erisichthe ziphioides, Cope, 1877, Bull. Geol. Surv. Terr. vol. iii. p. 821.

CIMOLICHTHYS LEVESIENSIS, Leidy. (England.)

Saurodon Leanus, Agassiz, 1843, Poiss. Foss. vol. v. p. 102, pl. xxv^{c}. f. 30, 31; Dixon, 1850, Foss. Suss. p. 373, pl. xxx. f. 28, 29, pl. xxxii*. f. 10.

Cimolichthys levesiensis, Leidy, 1856, Trans. Am. Phil. Soc. 1860, vol. xi. p. 91.

CIMOLICHTHYS MARGINATUS?, Reuss. (France and Bohemia.)

Spinax marginatus, Reuss, 1845, Böhm. Kreide, p. 8, pl. iv. figs. 10, 11.

Anenchelum marginatus, Hébert, 1854, Mém. Soc. Géol. Fr. ser. 2, vol. v. p. 350.

CIMOLICHTHYS? STRIATUS, Agassiz. (England.)

Saurocephalus striatus, Agassiz, 1843, Poiss. Foss. vol. v. p. 102, pl. xxv^{c}. f. 17–20.

? *Saurocephalus striatus*, Dixon, 1850, Foss. Suss. p. 375, pl. xxxv. f. 5.

Protosphyræna striatus, Leidy, 1856, Trans. Am. Phil. Soc. 1860, vol. xi. p. 91.

Note.—Since the above was written, a valuable paper by Mr. W. Davies, of the British Museum, "On the Nomenclature of *Saurocephalus lanciformis*, of the British Cretaceous Deposits; with Description of a New Species (*S. Woodwardi*)," has appeared in the 'Geological Magazine' (dec. 2, vol. v. p. 254); and it is most satisfactory to find that, in so far as we treat of the same subject, we are in perfect agreement, except as regards the name which should now be adopted for the so-called *Saurocephalus lanciformis*. Mr. Davies is of opinion that the name *Protosphyræna*, proposed by Prof. Leidy, should not be adopted, inasmuch as it seems to indicate an affinity with *Sphyræna*, which does not exist, and he therefore would use Prof. Cope's name of *Erisichthe*. Although quite appreciating the cogency of my friend's reasoning, I could not but feel that this was a case in which the law of priority must be respected. Unwilling, however, to trust to my own judgment alone, I laid the matter, as clearly and fully as

I could, before Prof. Huxley and Mr. W. S. Dallas; and both these gentlemen unhesitatingly said the name of *Protosphyræna*, being the earliest, is the one which will undoubtedly have to stand. I have also had a conversation with Prof. Cope. He maintains that Prof. Leidy did not in 1857 sufficiently characterize his genus *Protosphyræna*, and therefore that his name must be ignored, and that of *Erisichthe* adopted. Prof. Leidy has given what he considers to be a sufficient reason for separating the English so-called *Saurocephalus* from the American ones; and by his reference to the figures and descriptions of Agassiz and Dixon, makes it perfectly clear to what he gives the name of *Protosphyræna*. This seems to me to be all that the laws of nomenclature demand. His species, *Protosphyræna ferox*, is also manifestly the type of the genus. I should not be justified, therefore, in altering the synonymy in the above list. The new species of *true Saurocephalus*, described in the latter part of Mr. Davies's paper, will have to be added to the list, thus:—

Saurocephalus Woodwardi, Davies. (Maestricht.)

Saurocephalus Woodwardi, Davies, Geol. Mag. 1878, dec. 2, vol. v. p. 254, pl. viii. figs. 1 & 2.

Oct. 12, 1878.

46. *On* NEW SPECIES *of* PROCOLOPHON *from the* CAPE COLONY *preserved in* DR. GRIERSON'S MUSEUM, THORNHILL, DUMFRIESSHIRE; *with some* REMARKS *on the* AFFINITIES *of the* GENUS. By HARRY GOVIER SEELEY, Esq., F.L.S., F.G.S. &c., Professor of Geography in King's College, London. (Read June 5, 1878.)

[PLATE XXXII.]

DR. THOMAS BOYLE GRIERSON transmitted to me for description three more or less perfect small skulls, which all belong to the genus *Procolophon*, instituted by Professor Owen for some small reptiles from the Tafelberg. Dr. Grierson's specimens were collected by Mr. Donald White from Donnybrook, Queenstown District, Cape Colony. They are contained in a hard red ironstone matrix, often crystalline, which is apparently concretionary, and invested one skull much in the same manner as the clay-ironstone of our own country often invests Carboniferous fossils. The matrix can be removed only in part, because the bones and the cavities between them are frequently filled with brittle and crystalline carbonate of lime. Hence the thin film of external bone is often broken away in the endeavour to develop the specimens.

PROCOLOPHON GRIERSONI, Seeley. (Pl. XXXII. figs. 1–3.)

Of this species but one example has been found. The skull is of subtriangular outline, as in many lizards; and, as in lizards, it is rather depressed and flattened above. The occipital region appears to be vertical; the eyes are a large oval, placed nearer to the back of the skull than is usual in lizards, and look outward and upward. The nostrils are nearly terminal, but look laterally, being divided from each other by the narrow ascending process of the premaxillary bones.

In the median line, from the premaxillaries to the supraoccipital region, the specimen measures $1\frac{6}{10}$ inch. The occipital region, which is slightly compressed on the left side, measures from the median line outward $\frac{6}{10}$ inch, so that the region was probably $1\frac{2}{10}$ inch wide. The greatest width of the skull was attained nearly at the back of the orbit, in a line passing through the foramen parietale, and results from the convex bulging of the malar bones, where the width may have been $1\frac{4}{10}$ inch. At the anterior corner of the orbit the transverse measurement is $\frac{6}{10}$ inch; while the width of the upward bars of the two premaxillary bones which divide the nares is $\frac{1}{10}$ inch. The upper jaw extends beyond the lower, and the upper termination of the premaxillaries and the adjacent part of the nasal bones are compressed so as to form a short anterior region, which looks obliquely upward and forward.

All the roof-bones of the cranium appear to be double. The foramen parietale is large, rounded, and slightly elongated longitudinally, but less than $\frac{1}{5}$ inch in length. Its hinder margin is distant $\frac{7}{20}$ inch from the transverse occipital margin, and its anterior border is about $1\frac{1}{10}$ inch from the extremity of the snout. Behind the foramen the parietal, postfrontal, and squamosal bones are expanded as in the marine Chelonia; but in *Procolophon* the occipital region is closed posteriorly, as in Dinosaurs and Dicynodonts, which is not the case in the Chelonia; and the roof of the skull is encroached upon by the backward position, obliquity, and large size of the orbits. The orbits are elongated ovals, the hinder margins of which are in a line with the back of the foramen parietale, $\frac{7}{10}$ inch in length and $\frac{5}{10}$ inch in depth from the frontal to the malar. The anterior margin of the orbit appears to be pierced with a large lachrymal duct. The orbits appear to be margined by the maxillary and malar bones below; the postfrontal, which is very large, by its expansion seems to have filled in the vacuity between the parietal and squamosal; it forms the back of the orbit. The frontal divides the orbits; where narrowest it is about $\frac{3}{10}$ inch wide; from the foramen parietale to its transverse junction with the nasal bones it measures $\frac{6}{10}$ inch. The prefrontals appear to be moderate, to form the upper anterior borders of the orbits, and to extend forward to the nasal bones; but as the substance of the bone is broken away and only obscure sutural lines remain to indicate its limits, this statement is made with some reserve. There are some indications that the orbits were parted by a septum, and probably they were conditioned much as are the orbital cavities of *Hatteria*. I have evidence that the base of the orbit in this genus was formed by a palatal plate, and that the eye must have reached back to the front wall of the somewhat large brain-cavity. The chief difference of the external orbital region from that of such a lizard as *Plestiodon* consists in the large size and backward prolongation of the orbit. The interspace between the orbit and narine is $\frac{1}{20}$ inch. The portion of the skull anterior to the orbit has an aspect as of side-to-side compression. The nares are small, oval, and vertical, and lie between the premaxillaries in front, the maxillaries behind, and the nasals above. The narrow premaxillaries extend up so as to be embraced by the nasal bones, and only form a narrow band anterior to the nares. The teeth in each of the premaxillaries are four in number, two prehensile teeth close together in front of the nares (one in each bone) and three behind. In the maxillary bone of the right side are six teeth. These teeth are subcylindrical, and terminate in sharp conical points; they are placed close together, so that the expanded bases are almost conical. The hindermost tooth is $\frac{8}{10}$ inch from the extremity of the snout. The teeth have a central pulp-cavity which extends high up into the crown. At the base of each maxillary tooth appear to be many germs of successional teeth, which extend backward obliquely from the bases of each. Behind the teeth the maxillary bone appears to terminate in a downward process. The malar bone is about $\frac{1}{10}$ inch deep in front, but widens behind by rising so as to narrow the orbit posteriorly, and looks obliquely outward and upward. At the back of the malar bone the vertical narrow quadrate bone is attached; it is nearly $\frac{4}{10}$ inch in length, and sends inward and forward a large thin process similar to that of *Hatteria* and of Dinosaurs. Upon the quadrate bone appears to be a plate of bone (regarded by Prof. Owen as the squamosal), which I am inclined to regard as the quadrato-jugal; it extends chiefly behind the quadrate bone. Posterior to the quadrate bone the cranium is contracted a little, and probably excavated in the auditory region. The rami of the lower jaw are loosely adherent, and have a narrow union; they are straight, and diverge at a considerable angle. There are ten teeth in each ramus; the teeth in front are longer and more slender than those behind, as in many lizards. Immediately behind the teeth is a moderate coronoid process, and behind this the jaw thickens considerably from side to side, so as to extend outward somewhat after the manner of the lower jaw in some rodents. In the articular region the lower jaw is inflected a little, so as to widen the articulation. The extreme length of the lower jaw is $1\frac{4}{10}$ inch, but it extends a little behind the quadrate bone and terminates in a rounded and contracted heel. The depth of the jaw increases slowly from before backward, but where deepest is not more than $\frac{3}{10}$ inch at the coronoid eminence. The cervical vertebræ remain attached to the specimen, and are partly exposed by a fracture, so as to show indications of four or five. The centrums are rather short; the articular surface of the last is concavely or conically cupped with a central notochordal depression or perforation similar to that figured by Prof. Owen as Dinosaurian in Quart. Journ. Geol. Soc. vol. xxxii. pl. v., but which is paralleled in *Hatteria*, as well as in Amphibians and fishes. The neural spine of the first vertebra exposed is expanded from front to back, and the neural spines of the succeeding vertebræ are strong and directed backward as in *Hatteria*; short transverse processes are given off on a level with the base of the neural canal. To these processes slender cervical ribs were attached; but there is no evidence as to whether the articulation was single or double. The vertebræ are bent at a right angle with the roof of the skull, as in many mammals, ornithosaurs, and other animals. Below the vertebræ, and behind the lower jaw, is a portion of a thin expanded plate of bone, which is probably part of the sternum, in front of which are fragments of long bones, too imperfect for determination. As compared with *Procolophon trigoniceps* of Prof. Owen, which is of similar size, this species has the head much more compressed from side to side, more elongated in front of the orbits, has the parietal foramen smaller, and shows various minor differences which are more easily gathered from a figure than from description.

PROCOLOPHON CUNEICEPS, Seeley. (Pl. XXXII. figs. 7, 8.)

The second skull is somewhat larger and deeper, and the modification of the malar arch is so different from that seen in the first specimen, and in those figured by Professor Owen, as to leave no reasonable doubt that the animal is specifically distinct; and so, especially as it throws light on the palatal characters of the genus, the specimen may be deserving of description, although it is less perfectly preserved than the other. It was almost hidden in an ironstone nodule, from which I have, by the permission of Dr. Grierson, extracted it.

Like all the other crania of *Procolophon*, this skull is flattened above and of triangular outline; but in the median line it is rounded from the nasal region above down to the anterior termination of the palate, and in front of the orbits appears to taper rapidly, though this may result partly from accidental lateral compression. The bone-tissue is entirely removed from the front part of the skull; and on the left side the circular narine, $\frac{2}{10}$ inch in diameter, is seen to have looked downward and outward; the nares extend to the extremity of the skull, much as in *Uromastix*, and, though separated by the premaxillaries, do not appear to have been divided by a vertical bony septum. There is a slight compression behind the nares, and then succeeds the region of the lateral preorbital inflation, bounded above, on the cast, by two ridges which converge forward. These ridges terminate backward in a line with the narrowest part of the frontal bone, which is between the orbits, and they are prolonged forward to the anterior termination of the skull. From the front of the ovate foramen parietale to the end of the snout measures $1\frac{5}{20}$ inch. The least width of the frontal bone is $\frac{4}{10}$ inch. The posterior borders of the orbits are in a line with the hinder limit of the parietal foramen. The length of the orbit is $\frac{8}{10}$ inch; from above downward it measures $\frac{5}{10}$ inch. The upper surface of the skull is an inch wide behind the orbits; but the malar arch bulges outward and the skull reaches its greatest width at the articular portion of the quadrate bone. The malar bone originates at the anterior border of the orbit, and is a flat thin bone less than $\frac{2}{10}$ inch deep. At the middle of the orbit it bends, and widens in a triangular form, extending above and below so as to reach along the entire height, $\frac{8}{10}$ inch, of the quadrate bone. The length of the malar is rather more than its height; it is concave from above downward in its expanded hinder part, where it joins the quadrate bone, which in side view was vertical, though directed somewhat outward. The malar bone shows no certain sign of division, or evidence that it included a quadrato-jugal element. Many lizards with a complete orbit, such as *Calotes*, have the malar bone expanded and reaching far back, and joined by ligament to a thin wing of the quadrate bone, which curves outward and forward towards it, approximating towards the condition seen in these fossils. Resting upon the hinder part of the malar bone, and resting upon it superiorly so as to form the oblique hinder and inferior border of the orbit, is a thin bone $\frac{1}{10}$ inch deep and from $\frac{6}{10}$ to $\frac{7}{10}$ inch long, which occupies the usual position of the postfrontal bone in lizards, and appears to underlap the outer wing of the frontal bone at the hinder and upper limit of the orbit, on the lizard plan, but is in the position of the quadrato-jugal in *Hatteria*. The broad flattened superior surface of the skull behind the orbits ($1\frac{2}{10}$ inch wide), without trace of a temporal fossa, and formed by the frontal bones which partly overlap the parietals, is an important difference from the character of that region among lizards, which is always marked by a more or less conspicuous temporal fossa; but the variable condition of this region in the Chelonia warns us that the expanded forms of the parietal and frontal bones roofing-in the head need not be more than a generic difference in the Lacertilian order. Probably owing to the condition of preservation of the specimen, there are no indications of teeth in the premaxillary bone; but indications of the posterior seven teeth are preserved: they are large, long, cylindrical, tapering to a conical point, which is slightly recurved; each has a large pulp-cavity, prolonged into a short canal, which appears to pierce the crown of the tooth. The teeth are ankylosed to the jaw without trace of fangs or sockets. A fracture through the middle of the specimen shows the palate in the region beneath the orbits to be closed in the median line. The middle region is occupied by rows of teeth, short and conical, which converge forward in a V-shape. Seven teeth in a row on one side in the inner and hinder series on this part of the palate are visible in the space exposed. External and anterior to these teeth there are indications of another parallel series, of which three crowns can be detected. These teeth must be placed on the pterygoid bones. On each side of the teeth the palate is broadly channelled, and the transverse process of the pterygoid which forms the channel is broad and prolonged outward and downward, being homologous with the outer and downward processes of the pterygoid bones of the crocodile. Coupled with the fact that the pterygoid in the specimen previously described must have reached the quadrate bone, this condition of the palate is essentially Lacertian. Below the palate is a mass of bone, which seems too thick to be the central element of the hyoid; but at the posterior end of the skull, in a corresponding position, are two slender, parallel, cylindrical bones, which would lend support to such a view.

PROCOLOPHON LATICEPS, Seeley. (Pl. XXXII. figs. 4–6.)

The third skull of *Procolophon* is larger and relatively much broader. All the hinder part is invested in matrix. It is fractured obliquely behind the foramen parietale, so as to give some indication of the transverse outline of the brain-cavity and of the position of the pterygoid bones. The skull extends markedly beyond the lower jaw both anteriorly and laterally, and the teeth in the maxillary bone are directed inward just as those in the lower jaw are directed upward and outward to meet them. There would seem to have been a very slight displacement of the rami at the symphysis; but this is probably more the result of crystallization going on in the matrix than of pressure, since the specimen shows no evidence of deformation. This species, in common with the others, has a flattened upper surface, cranial bones in pairs, a rounded snout terminated by a pair of narrow premaxillaries, nares similarly placed and looking downward laterally, large oblique orbits, similar inflation of the lachrymal or preorbital region, and subcylindrical teeth ending in conical points; so that it is distinguished chiefly by its form and measurements from the species already described. From the anterior border of the pear-shaped foramen parietale to the anterior limit of the premaxillaries is fully $1\frac{2}{10}$ inch. Between the orbits the frontal bones measure, where narrowest, $\frac{4}{10}$ inch. The antero-posterior extent of the orbit is $\frac{7}{10}$ inch. The snout is rather blunt, and the ridges on the cast, which are prolonged from the upper corners of the orbits to the anterior nares, are parallel to each other, and diverge slightly outward as they terminate forward, instead of converging. The nares are rather small ($\frac{1}{10}$ inch), and look outward and downward, without any forward tendency. The front of the premaxillary bones is covered by matrix; but laterally on the right side the bone is separated from the maxillary by a somewhat oblique suture, which descends with a backward inclination from the hinder border of the nostril to the palate, and contains on its lateral aspect three large long teeth with pulp-cavities. In the maxillary bone are seven similar teeth, further apart behind than in front, but never separated by interspaces so wide as the teeth. The length of jaw occupied by the ten teeth and their interspaces is $\frac{7}{10}$ inch. The bases of the fangs are invested by bone, so as to have the aspect of being in sockets. In the corresponding part of the lower jaw, extending for $\frac{4}{10}$ inch, are six cylindrical teeth, which decrease in length backward; the front ones are fully $\frac{3}{20}$ inch long. The teeth are smooth, without a trace of striations. The maxillary bone is convex from above downward; it is pierced by a large oval foramen, which is above and behind the second maxillary tooth. Above the maxillary bone, and extending under it so as to form the anterior corner of the orbit, is the large lachrymal or prefrontal bone, which covered the preorbital inflation and joined the nasal bone. The width of the skull at the outward bend of the malar bone, which is much sharper than in other species, is about $1\frac{8}{10}$ inch. The height of the skull, including the lower jaw, is $1\frac{2}{10}$ inch. The lower jaw is strong and deep, and increases in depth from before backward; it is flattened, compressed from side to side, and straight; but beneath the quadrate bone it becomes wider than deep, and is subquadrate in section where it is fractured through; it extends for a short distance behind the quadrate bone, and is rounded and compressed from above downward. The dentary bone is large, and on its inner side the splenial bone extends to the anterior extremity. The quadrate bone is vertical, overlapped in front by the quadrato-jugal, which curves round, much as in chelonians, so as to cover its lateral aspect, except at the articulation. Above and in front of the quadrato-jugal is the malar, which forms the lower and hinder border of the orbit. Both these bones extend upward almost to the roof of the skull to meet a squamous bone, apparently the squamosal, which overlaps the parietal, reaches forward to the hinder margin of the orbit, becomes massive behind, and extends over the strong transverse element at the back of the skull, which can only be one of the otic bones, probably that called paroccipital by Professor Owen. The upper part of the quadrate bone is wedged into a vertical bone, which extends inward and forward so as to form the back wall of the orbit, but does not visibly enter into the wall of the brain-case. This bone is evidently a downward fold of the parietal, and in meeting the quadrate offers a modification which is paralleled to some extent among Lizards and Rhynchocephalians. The quadrate bone is also developed outward into a large, vertical, cellular mass, which extends outward for $\frac{3}{10}$ inch beyond the articulation for the lower jaw, is behind the quadrato-jugal, and increases the transverse width of the skull to $2\frac{2}{10}$ inches, which is considerably more than its length. The pterygoid process of the quadrate is thin, is directed inward, upward, and forward, and is given off at more than $\frac{2}{10}$ inch above the articular surface of the quadrate bone; it may extend inward for about the same distance. The pterygoid bones meet in the middle line, and are prolonged backward and obliquely downward to a level with the articular pedicles of the quadrate bones; they are not in contact with the base of the brain-case.

The vertical fracture through the brain-case is somewhat oblique. This cavity appears to have been $\frac{4}{10}$ inch deep in the sphenoidal region, and slightly narrower; and, as in most reptiles, it is like a box contained within the skull *. The basisphenoid is thick and channelled on its ventral aspect, two strong compressed hypapophyses being prolonged downward and backward towards the pterygoid bones. The alisphenoid is thick and directed upward and outward; there is a large perforation placed between it and the bone above; and, since the perforation opens into the back of the orbit, it probably gave passage to the optic nerve, so that the bone would be the frontal. It is uncertain whether the brain-case was closed in above by bone, no bone being visible in the upper median part of the cerebral region. The fracture in the specimen gives no evidence concerning the existence of a columella.

The Systematic Position of Procolophon.

Such being the more important structures of the skull of the genus *Procolophon*, it remains to determine the place of the type in the Reptilian series. Professor Owen placed the genus in the family Mononarialia of his order Theriodontia, the family being defined as having "the external nostril single or undivided," and with more than three incisor teeth in each premaxillary bone. The more perfect preservation of the nasal region in the specimens described, by

* The specimen figured by Professor Owen in his South-African Reptile Catalogue, pl. xx. fig. 2, as the brain-cavity of *Nythosaurus larvatus* may be seen, by comparison with the lateral view of the same specimen (pl. xx. fig. 1), to represent the whole interior cavity of the skull from the brain forward to the nares. There is no evidence that the cavity for the cerebrum extended forward between the orbits, as indicated in the figures and text (p. 24). This apparently mammalian character would also result from a modification of the Chelonian plan of a median prolongation forward of the chamber for the envelope of the brain.

exhibiting divided external nostrils, demonstrates that the genus cannot be located in the Mononarialia. The only definition of the order Theriodontia is that given by its illustrious founder in these words *:—" Dentition of the carnivorous type; incisors defined by position, and divided from the molars by a large laniariform canine on each side of both upper and lower jaws, the lower canine crossing in front of the upper as in Mammalia." But since *Procolophon* possesses no canine, and exhibits no modification in the dental series of any importance from front to back of the jaw, it is obvious that the genus does not conform to the dental definition of the Theriodontia, even if an ordinal group could be founded on such characters as have been cited. Before inquiring whether the Theriodontia can be defined so as to include *Procolophon*, I would remark on the very small value which can be attached to modified form of teeth as an ordinal character. It is extremely rare to find that the teeth do not change their form and proportions with position in the jaw. In Lizards and Crocodiles these modifications so far parallel those of the supposed Theriodonts as to be worth some consideration in searching for the classificatory value of the mammalian type of teeth found in the South-African fossils. In *Hatteria* and in a large number of lizard types there are teeth which are more or less well defined by position and altered form as incisors, premolars, and molars; but the canine attains no development, and sometimes the character is more strongly marked in the lower than in the upper jaw. Yet it would be altogether unjustifiable, in the present state of science, to see more than an analogy between these lizards and corresponding ordinal types of dentition among Mammalia; for it would presuppose that the teeth remained comparatively unchanged, while the remainder of the organism scarcely retained a semblance of lizard characteristics; whereas it is known, from the evolution of all the orders of Mammalia during Tertiary ages †, that the axial skeleton alters with extreme slowness, while the rapid modifications of the mammalian teeth are even more striking than the changes seen in bones of the limbs. But, among the Crocodiles, I recognize in the well-known wavy outline of the jaws a demarcation of teeth into regions which have a fair right to be named incisors, canines, premolars, and molars, and constitute a dentition as Theriodont in principle, but not so specialized, as is seen in the South-African fossil group. In the crocodile the regions are easily recognized by the form, size, and characters of the tooth-sockets, when all the teeth are drawn, especially in the lower jaw. The incisors occupy a flat or slightly concave region, corresponding to the premaxillary bone. Then at the head of the crest is the large canine placed between the premaxillary and maxillary bones. Next succeeds a portion of jaw with concave outline occupied by small teeth, which sometimes become larger from before backward: these are the premolars. And, lastly, there are teeth in another concave region which have the position of molars; these may, in the young animal, all be con-

* 'Fossil Reptilia of South Africa,' 4to, 1876, p. 15.
† See Gaudry, 'Mammifères Tertiaires,' 8vo, 1878.

tained in a groove with sockets scarcely better indicated than among Ichthyosaurs.

Fig. 1.—*View of Lower Jaw of a Crocodile, from above, showing the formula* I. 3, C. 1, Pm. 6, M. 9.

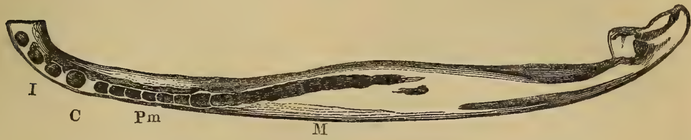
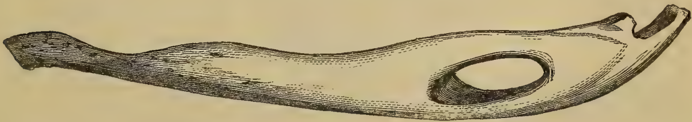


Fig. 2.—*Lateral View of the same Jaw, showing how these Regions are indicated by Curves.*

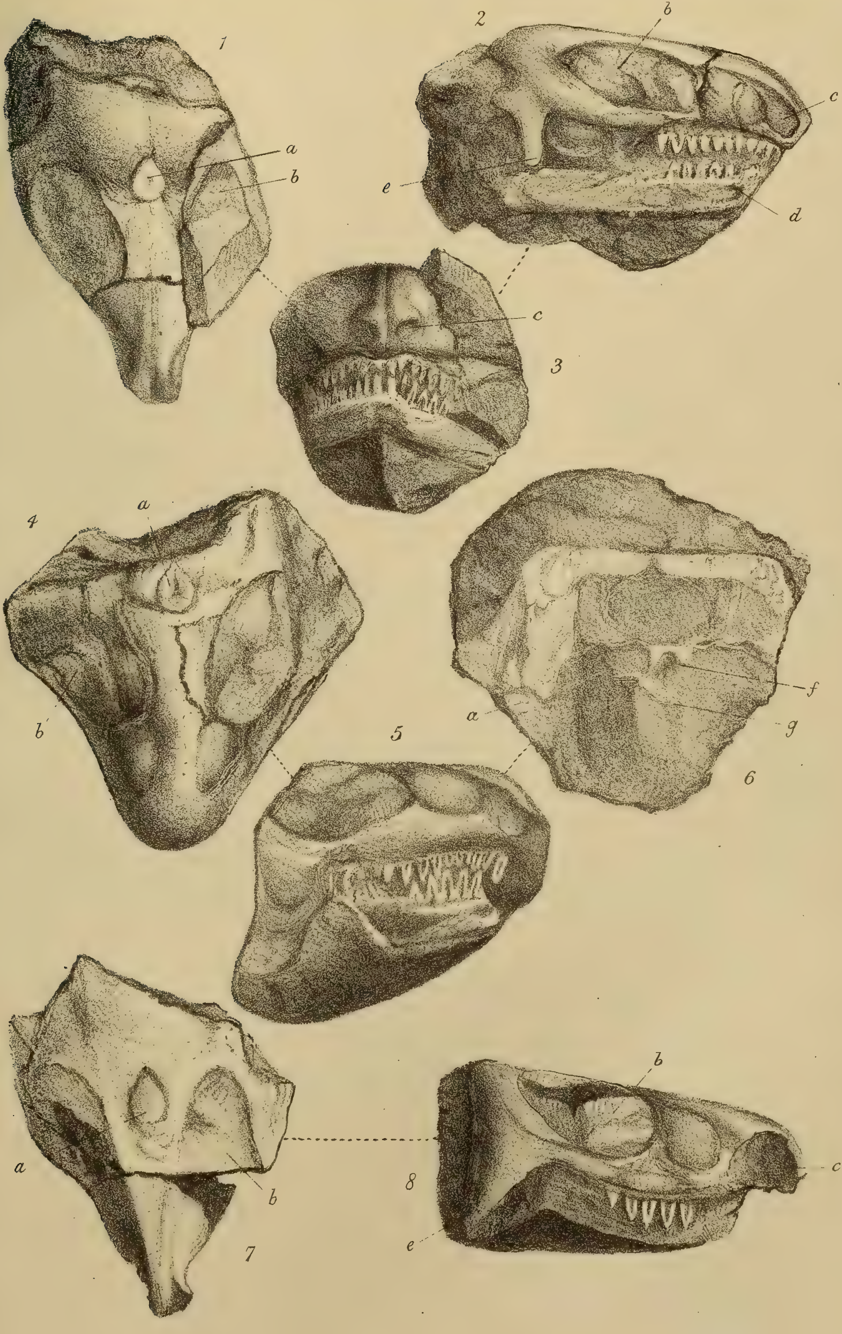


Nor are Crocodiles the only animals in which this sort of dental character is met with; for it may be detected more or less well marked, though with different divisions, in certain Plesiosaurians, some of the Ornithosauria, and Teleosaurs *. It is true that no other types, of reptilian affinities, have the canines so much developed as in the so-called Theriodonts of South Africa; but when we remember the wide range of variation in dental characters that exists among marsupial mammals, coupled with the variation of size in the canines of Carnivora, there seems to be a *primâ facie* objection to the institution of an ordinal group for reptiles with canine teeth, even though they may sometimes be as well developed as in *Machairodus*. If the order is well founded, it will show cranial and other characters which are more important. The South-African genera classed as Theriodont by Prof. Owen are largely founded on snouts, which give no indication of the structures of the skull which are useful in comparison: among such genera are *Tigrisuchus*, *Cynodraco*, *Cynochampsa*, *Cynosuchus*. The genera founded on more or less useful crania are:—*Lycosaurus*, which is too imperfect for comparison; *Procolophon* and *Scaloposaurus*, neither of which fall within the definition of Theriodonts, since they have no canine teeth; and, lastly, *Galesaurus* and *Gorgonops*, genera which differ a good deal, of which the former shows the limits of the bones on the upper surface of the skull, and the latter gives imperfect indications of the structure of the palate (which, though figured, has not been described). These palatal structures are similar to those figured in *Ptychognathus boopis*, and appear to be such as

* Continental naturalists have long used the mammalian formula for teeth in describing Teleosauria (see Pictet, 'Traité de Paléontologie,' vol. i. p. 484, *et seq.*).

might well be included under the Dicynodont type. The typical forms of this group, such as *Dicynodon testudiceps*, have the anterior nares almost as far forward as in the Theriodonts; and there is a sufficiently close resemblance between the lateral aspect of the skull in *Gorgonops* and that of such a species as *Dicynodon lacerticeps* to show that there is no character of importance, beyond the single premaxillary bone in *Dicynodon* and the divided premaxillary in *Gorgonops*, to place the genera in different groups. Nor is the skull of *Galesaurus* so unlike that of the *Dicynodon pardiceps* in form and position of the bony elements as to necessitate their location in different orders. In fact the Theriodonts differ from the Dicynodonts much as these differ from Oudenodonts. If the Theriodonts are taken as the typical form, with all the teeth developed, then the Dicynodonts are those genera in which the incisor and post-carnassial teeth disappear; and the Oudenodonts are the genera in which all the teeth disappear, or are but slightly developed. A fourth family may perhaps be indicated by *Endothiodon*, in which the palate is covered with palatal teeth closely placed and irregularly grouped. Professor Owen long ago characterized the first three families just referred to under the excellent names Cynodontia, Dicynodontia, and Cryptodontia, which he regarded as making up the order Anomodontia*. I cannot find any evidence that the characters by which the Cynodontia differ from the other families are such as would justify the institution of an ordinal group for them; and therefore urge that the name Theriodontia must rank as a synonym of the family name Cynodontia. *Procolophon* can only be placed among the Cynodontia on the hypothesis that it is a modification of that type in which the canine teeth have not become separable from the others; but I should prefer to regard it as belonging to a parent type from which the dental modifications of the Anomodontia have been derived. And in that view there seem to me to be no sufficient reasons for regarding the genus as other than an extinct family of the Rhynchocephala. Professor Owen fully recognized the affinity of the Dicynodonts in this direction when they were first described; and therefore this suggestion of affinities only raises the question whether the Anomodontia and the South-African animals described as Dinosauria perhaps might not be united with the Rhynchocephala into a subclass of Reptilia. Of the affinity of *Procolophon* with the Anomodonts there can be no great doubt, though there is no conclusive demonstration; but, in common with the Rhynchocephala, it has (1) a fixed vertical quadrate bone, which (2) sends a process inward and forward to articulate with the pterygoid, and (3) develops a strong process which extends outward transversely to the main column of the bone and above the articulation; (4) both have teeth on the bones of the palate, though apparently not on the same bones, and the pterygoid bones are more closely united in the fossil than in the living type; (5) in both there are large, long, palatal vacuities beneath the anterior nares, such as also occur in Lizards; (6) both types have the skull of

* See Owen's 'Palæontology,' 2nd ed. p. 256 *et seq.*



Redaway lith.

Hanhart imp.

PROCOLOPHON.

the same general form, and the median roof-bones double, with orbits, nares, and foramen parietale similarly placed. The chief differences are that (1) in the fossil the region of the temporal fossa is covered by expansions of the frontal, parietal, and postfrontal bones; but since in *Podocnemys* this is only a generic variation from the Emydian type, there is no reason for attributing more than generic importance to it in the fossil; (2) the malar bone in the fossil is expanded so as to cover most of the vacuity which exists in the living type between that bone and the squamosal; (3) in the fossil the posterior outline of the skull is straight. There are many important points upon which further information must be obtained before the position in the series of *Procolophon* can be finally settled; but, in the present state of knowledge, I see no reason to hesitate, on the evidence detailed, in regarding it as a fossil Rhynchocephalian. As such, it adds another link to the evidence that the Rhynchocephala constituted one of the most widely diffused types of terrestrial life in the Triassic period.

EXPLANATION OF PLATE XXXII.

Procolophon Griersoni.

Fig. 1. Skull, seen from above.
Fig. 2. Lateral view of same skull with lower jaw.
Fig. 3. Anterior view of skull, showing divided nares.

Procolophon laticeps.

Fig. 4. Anterior part of skull, seen from above.
Fig. 5. Lateral view of same skull.
Fig. 6. Vertical section of same skull through quadrate bone, lower jaw, brain-cavity, basisphenoid and pterygoid bones.

Procolophon cuneiceps.

Fig. 7. Skull, seen from above.
Fig. 8. Lateral view of same skull.

(*a*, parietal foramen; *b*, orbit; *c*, nostril; *d*, lower jaw; *e*, quadrate bone; *f*, basisphenoid; *g*, pterygoid bone.)

Discussion.

Mr. Hulke accepted Prof. Seeley's views on the structure of the skull of *Procolophon*, and agreed with him as to the difficulty of regarding the Theriodontia as forming a distinct Order of the Reptilia.

47. *On a* Section *through* Glazebrook Moss, Lancashire.

By T. Mellard Reade, Esq., C.E., F.G.S. (Read June 19, 1878.)

The Wigan Junction Railway now being constructed runs, for the length of a mile, through Glazebrook Moss. Walking from Glazebrook Station, on the Cheshire Lines Railway, towards Kenyon Junction, on the old Liverpool and Manchester Railway, we come, in about half a mile, upon the edge of the Moss, and here the Wigan Junction Railway goes through it in a cutting. In the deepest part the moss is about 18 feet from the actual surface to the boulder-clay on which it rests; but the drainage produced by the cutting has caused the moss to sink from 7 to 8 feet on either side in its vicinity.

The bulk of the moss is of the ordinary nature, and looks, on drying, more like sawdust than any thing else. Near the base, for 3 or 4 feet upwards, are the remains of trees—branches imbedded in the peat. Where the peat has been excavated down to the boulder-clay the stools of trees, in the position they had grown in, are now to be seen; they are, with one exception, so far as I saw, either oak or birch; and the whole of the peat being removed from about them shows very plainly the roots penetrating into the clay. The upper layer of clay is of a grey colour, and is evidently the top-wash of the boulder-clay. A splendid prostrate trunk of an oak was bared when I viewed the cutting; it measured 46 feet long as far as exposed, and was fully 3 feet in diameter, without the bark, in the straight part of the trunk above the root. A very strong root was attached to it. The tree had evidently been uprooted by being blown over; it was lying in a north-easterly direction. I calculate there was 200 cubic feet of timber in the exposed part. The trunk was very straight and free from branches.

Mr. Lambert, the contractor's agent, informed me that another trunk had been found of the same diameter and 60 feet long. The wood, on being cut into, was very wet and of a very bright orange-yellow, but on being exposed to the air for a few hours the surface became dark brown. At first sight the timber looked very unlike oak.

At the south end of the Moss the surface-level is 59·46 feet above Ordnance-datum; and at the north end the natural surface of the clay land is 60·31 feet above same datum. The summit-level of the Moss is 78·70 feet; the surface of the Boulder-clay is therefore nearly level, and the Moss is like a protuberance upon it: this is the reason it has had to be cut through. It is probable that the accumulated decay of the forest and change of climate * have produced the Moss;

* In my "Post-Glacial Geology of Lancashire and Cheshire" (Proc. Liverpool Geol. Soc. Session 1871–72, p. 73) I suggested that the remains of these ancient forests are the representatives of continental conditions and a drier climate

for there seems no other reason why the Moss should be in this particular spot and absent on the boulder-clay land at the same level surrounding it than the preexistence of the forest on the site of the Moss. It is also probable that the Moss, commencing at a nucleus of forestal decay, has pushed itself outwards, as one of the first trees I tried near the edge of the Moss was an ash, very little discoloured by peat and quite sound.

This tree could not have been so long imbedded in the peat as those near the centre, and may have been engulfed by the bursting of the Moss. At the northern edge of the Moss stunted birches are growing in it, exactly similar in the bark to those imbedded in the peat.

The Boulder-clay extends over the whole length I walked, viz. six miles.

Just south of the Liverpool and Manchester Railway there is a fine section of the Boulder-clay, about 20 feet deep. It is, as commonly happens, divided by a thin seam of sand, very persistent, the clay above being 12 feet deep in the thickest part, and about 4 feet in the thinnest. The clay above this breaks off with a grey fracture, showing a very distinctive difference from that below; but both are very free from stones.

I attach no geological importance whatever to these distinctions: the difference in the upper clay is simply produced by drainage caused by the sand-seam, and fractures by shrinkage down to it. These grey fractures always go to the nearest sand-seam, seldom below it; they are merely the result of deep natural subsoil drainage.

Beyond the bridge, at 5 miles 78 chains, near Byram Lane, there is a bed of laminated clay (book-leaf) in the Boulder-clay at the bottom of the cutting, about 8 feet from the surface, which has been penetrated 18 inches deep; it extends about a quarter of a mile. The laminations are very fine, and are nicely preserved in the lumps of burned ballast made from the clay.

About 1 mile 32 chains, near the northern edge of the Moss, a boring showed 7 feet of clay and soil and 27 feet of gravel (unbottomed). At 1 mile 55 chains another boring showed wet sand 8 feet, stiff clay 6 feet, wet gravel 9 feet 6 inches, and then sandstone penetrated 4 feet. At 2 miles another boring showed 6 feet dry sand, 11 feet gravel, 11 feet strong clay, and then sandstone. The surface-levels were all between 60 and 65 feet above Ordnance-datum. The summit-level of the Boulder-clay was 119 feet above Ordnance-datum in the length I traversed, and at 4 miles 20 chains*.

In the Boulder-clay Mr. Beloe (the engineer of the line), who kindly called my attention to the section, informs me he found the trunk of a tree deeply imbedded; the spot was pointed out to me. The timber was said to be oak, 6 feet long and about 14 inches diameter, imbedded vertically, the lower end about 9 feet below the surface, and the clay undisturbed about it. This is the first instance I ever heard of timber in the marine Boulder-clay of Lancashire. If genuine, it must have been drift timber.

* All the distances given are from the junction at Glazebrook station.

A comparison of this inland moss with the peat- and forest-bed at the Alt mouth is very instructive*. In the latter there is a much greater variety and profusion of trees, though none so large as the oak I have just described. The peat is also much harder and more compressed, and the bottom contains more bark and branches.

It is not improbable that the sandhills, which must have been formerly at the top of the Alt-mouth peat, but are now washed away, have assisted to compress it, the sound branches even being compressed into an oval section. It is much older and of longer growth than the inland moss just described. There has been a succession of trees, and the timber itself bears marks of greater antiquity.

* "The Submarine Forest at the Alt Mouth," Quart. Journ. Geol. Soc. vol. xxxiv. pp. 447, 448.

48. *On the* Metamorphic *and* Overlying Rocks *in the Neighbourhood of* Loch Maree, Ross-shire. By Henry Hicks, M.D., F.G.S. (Read May 22, 1878.)

In a paper communicated to the Geological Society on December 5th, 1860 (and published in vol. xvii. p. 85 of the Quarterly Journal), by Professor Nicol, a section on the north side of Loch Maree is given, with the order of succession of the rocks and their supposed relations to the underlying metamorphic series. This section is there referred to by him, with others, as offering evidence in the support of views which he had previously communicated to the Society, and as opposed to the idea of a conformable upward succession from the limestone series to the so-called Upper Gneiss of Sir Roderick Murchison. The section is taken in a direction from W. to E., and the following is the order in which the rocks are described:—*a*, gneiss; *b*, red sandstones unconformable on *a*; *c*, quartzite conformable on *b*; *d*, limestone conformable on *c*; *s*, diorite (intrusive); then a fault; and beyond this the western gneiss, *a*, again brought up by the fault.

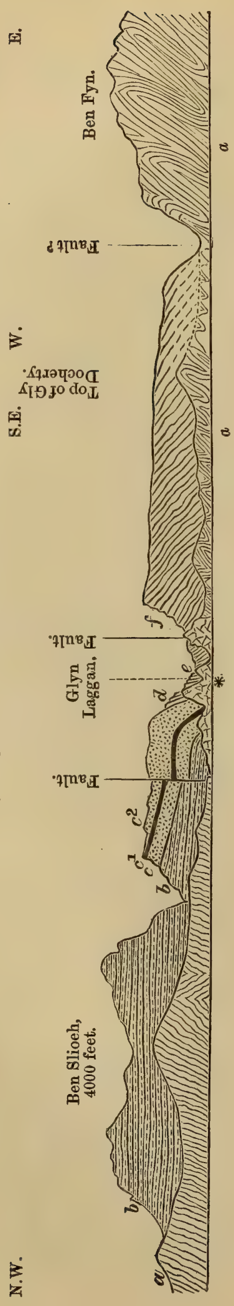
On February 6th, 1861, Sir R. Murchison and Mr. A. (now Professor) Geikie communicated a paper also to the Geological Society (Quart. Journ. Geol. Soc. vol. xvii. p. 171), in which the same section along the north side of Loch Maree is given, but with a very different interpretation in some important points from that previously given by Professor Nicol. They give the following as the order of succession from W. to E:—*a*, gneiss; *b*, Cambrian sandstones unconformable to *a*; c^1, quartz rock unconformable to *b*; c^2, limestone; *s*, syenite, intrusive along the bedding; *d*, gneissose schists conformable to and hence higher in the succession than c^2, and with no fault between; the ascending order being "here, as everywhere to the north, quartz-rock, limestone, and upper flaggy or schistose beds" (*l. c.* p. 192).

It will be seen at once how entirely at variance the views above given are, and hence how important all information which may in any way tend to elucidate the matter must be. As I have recently had a favourable opportunity of examining this section, and as the results have been such as to lead me to a different interpretation from that given in either of the above views, I now venture to lay them before the Society.

Sir R. Murchison and Mr. Geikie, in speaking of this neighbourhood in the paper referred to, say:—"Loch Maree, one of the wildest of Scottish lakes, presents a series of sections of singular clearness. With Kinloch Ewe as his head-quarters, the geologist has a wide sweep of interesting ground around; him and we know of no locality where he may better acquaint himself with the order of superposition of the ancient crystalline rocks of the Highlands, or with the dislocations and metamorphism which they have undergone." Hence it is evident that this section, in their opinion,

Fig. 1.—*Section from the north side of Loch Maree to Ben Fyn near Auchnasheen.*

(Length about fifteen miles.)



a. Pre-Cambrian: Gneiss, hornblende-schists, mica-schists, &c.
b. Cambrian: Conglomerates, grits, sandstones, shales, &c.
c, c^1, c^2. Sandstones, flaggy beds, quartzites, &c.
* Granite, syenite, &c.

d. Limestones, calcareous sandstones, &c. *e.* Blue flags, sandstones, &c. *f.* Argillaceous, quartziferous, and micaceous flaggy beds. } Silurian.

may be considered typical of the order of succession as exhibited generally in the Western Highlands, and that a clear interpretation of it, therefore, must have an important bearing upon many of the other areas examined by them.

The section (fig. 1) which I propose to describe is, like the others, for the first part along the north shores of Loch Maree and the heights of Kinloch Ewe, but is continued considerably further to the east. Up to a certain point, it will be seen that it agrees very nearly with that given by Sir R. Murchison and Mr. Geikie; but the subsequent portion is very differently interpreted.

The gneiss (*a*) occurs on both sides of the lake, and in its general character it resembles that in the neighbourhoods of Gairloch and Torridon. At some places, as immediately to the west of the Loch-Maree Hotel, it is highly quartzose; but between this and Gairloch dark grey gneiss and hornblende schists prevail. At Gairloch, immediately under the Cambrian conglomerate, a pure mica-schist is found. All these varieties may be seen along the roadside, and may be taken as typical, partially at least, of most of the series exhibited on the north shores of Loch Maree, from which our section is taken.

Resting unconformably on the gneiss, which dips here at a high angle and with a N.W. strike, are the conglomerates and sandstones (*b*) called by Prof. Nicol "red sandstone," and by Sir R. Murchison "Cambrian conglomerates and sandstones." They appear to have been, for the most part, shore or shallow-water accumulations; and fragments of the underlying gneiss rocks are abundant in them as pebbles or masses but slightly rolled. Associated with these, however, are other masses which do not seem to have come from the immediate neighbourhood, or at least from any of the areas which I visited. These are chiefly bits of greenish, purplish, and reddish slates, schists, jasper, &c., similar in many respects to those found in the Cambrian conglomerates in Wales, and which were there undoubtedly derived from the underlying Pebidian beds. It is therefore quite possible that in some other areas not far distant representatives of these Welsh pre-Cambrian rocks may also be found.

Looking at the conglomerates and sandstones in a petrological as well as stratigraphical point of view, I must say they appear to me to be on the whole exceedingly like the more shallow portions of the Cambrians of Wales, and to hold an equivalent position. The conditions at the time they were deposited were undoubtedly unlike in some respects, but generally they were the same. The lines of depression appear in both cases to have been alike and probably synchronous; but in Wales the submergence was greater, and hence the accumulations were, for the most part, of finer materials. The succeeding beds (*c*), quartz rocks, which, according to Sir R. Murchison, lie unconformably on the Cambrians, seem so here, though Prof. Nicol holds a contrary view. The dip and the general manner in which they lie are, however, imperfectly shown in Sir R. Murchison's and Mr. Geikie's section; and neither they nor Prof. Nicol mention the so-called fucoidal beds (c^1) which interstratify the quartz rocks here, and which they particularly refer to in some other sections. These are dark grey flaggy bands, of some thickness, and contain on their surfaces peculiar fucoidal-looking markings, similar to some occasionally found in the more shallow beds of the Lingula-flags and Tremadoc Rocks in Wales. These markings, of course, are not in any way sufficient to enable us to attempt to correlate the beds; but such facts are worthy of being remembered if only as guides to the conditions present at the time, and of the possible contemporaneity of changes affecting distant areas. Indeed it is almost impossible, when looking at these thick beds made up of pure quartz grains also, not to call to mind the Stiper Stones of Shropshire, which, if our reasoning is correct, must have been formed about the same period.

The second band (c^2) is probably nearest in position to the Stiper Stones; but the breaks above and below these quartz rocks, if they are really such, with the intermediate sediments, must actually bridge over the whole of the periods included under the names Menevian, Lingula-flags, Tremadoc, Arenig, and which are represented in Wales by from 8000 to 10,000 feet of sediments, with numerous and varied faunas.

Upon the quartzites are the limestone bands (*d*), occupying chiefly the sloping ground on the west side of Glyn Laggan; and the limestone, except where it approaches or is in contact with an intrusive mass, is everywhere in an unaltered state. In all sections across Glyn Laggan hitherto described a great mass of intrusive rock is shown

Fig. 2.—*Section across Glyn Laggan, about two and half miles N.E. of Kinloch Ewe.*

N.W. S.E.

For explanation of symbols, see fig. 1.

to separate the limestone entirely from the upper series of rocks (the so-called Upper Gneiss), and hence to occupy most of the low ground between the heights on either side. This, however, on careful examination, proved not to be the case; and a second series of sandstones, calcareous grits, and blue flags (*e*) were found to occupy the bed of the river and a considerable distance of the sloping ground on either side (see fig. 2).

Another arm of the invading mass* rises up to a height of 230 feet on the east side, and may be examined in the Denlochie torrent in contact with the next series. Prof. Nicol places a fault at this point, and says that the fundamental gneiss (*a*) is here brought up to give it an appearance of overlying conformably the unaltered series. I, however, hold, with Sir R. Murchison and Mr. Geikie, that the next (*f*) is a younger series, and that it overlies the unaltered beds; but I entirely demur to the view held by them that the rocks which compose this group as exhibited here should be called gneiss rocks, or associated in any way with those which have undergone the metamorphic change so characteristic of the pre-Cambrian rocks as known in this country, and which could only be induced, I believe, by influences to which it is evident these rocks, as shown by their position and undisturbed state, could not have been subjected, and which would occur mainly during periods of great depression combined with heat, moisture, and pressure.

* This invading mass varies considerably at different points, and it becomes difficult to give it everywhere a distinctive name. The term syenite, however, though not quite satisfactory, is, according to my friend Mr. Hudleston, the best general name.

On examination I found these upper beds everywhere unaltered, except near dykes, and the change there induced in them was that now well known as partial or contact-alteration, and which is so entirely distinct from true or general metamorphism. These beds all dip to the S.E. at a low angle, and attain a thickness of several thousand feet. They are flag-like in character, and are made up chiefly of fragmentary materials, but are occasionally slightly calcareous. They are much like some of the Lower Silurian flags in Wales, and are in no degree more highly altered than many of those rocks in the more disturbed districts. They may be traced along both sides of Glyn Docherty, but are dropped to a lower horizon on the south side by the fault which extends from here through Loch Maree in a line almost from N.W. to S.E. On the north side of the road in Glyn Docherty, about two miles from Kinloch Ewe, and almost at the base of the hill, the lower beds have been denuded by streams of water from the higher ground, the channels being, at the time of my visit, almost dry.

On examining these beds I found that the rocks were very unlike those along the hillside on the higher levels, and which I had traced forward continuously from Glyn Laggan. They were evidently much more allied to the gneiss of the west side of Loch Maree; and the strike proved to be, as in the latter, from N.W. to S.E., and hence in an entirely opposite direction to that in the higher beds. This offered the clue which enabled me afterwards to arrive at the conclusions which this paper is chiefly intended to convey.

This lower series in Glyn Docherty has apparently escaped the observation of all previous writers; and I was surprised to find, on further examination, that this discordancy in strike and dip was not confined to this one point, but that it occurred continuously for several miles, or at least from near Kinloch Ewe to what is called the top of Glyn Docherty, the highest point on the road to Auchnasheen. These gneiss rocks keep at a low horizon for about four miles, or until we reach the top of the Glyn. At this place they assume a reddish granitoid appearance, and ascend considerably higher into the hill.

For the next few miles they are traced with more difficulty, and probably faulted, but rise up again into the mountains as we approach Auchnasheen.

The upper or overlying beds (*f*) are entirely lost at the ravine which separates these hills from Ben Fyn and the range of mountains behind Auchnasheen. I was unable to trace the limits of these upper beds on the south of Glyn Docherty and of the valley of Loch Rosque; but from distant appearance I thought they extended further east for several miles on that side than on the north side. I had, previous to this, ascended Ben Fyn from Auchnasheen, and carefully noted the rocks which were there exposed. I was then surprised to find that they were almost identical in character with the gneiss rocks of Loch Maree and Gairloch.

I now again ascended Ben Fyn along a ravine a little N.W. of

Auchnasheen in which the rocks are beautifully exposed, and, after obtaining this clue to the arrangement of the rocks in Glyn Docherty, I soon became convinced that the whole of the mountain consists of the lower gneiss rocks, being altogether a highly crystalline series, chiefly gneiss with garnets, mica-schists also with an abundance of garnets, and some hornblende-schist.

I now noted the strike carefully as I ascended to a height of between 2000 and 3000 feet, and found it to vary only from the points N.W. to N., and hence generally in accordance with the gneiss of the west, and not, as has usually been supposed to be the case in the central Highlands, with a strike of from N.E. to S.W., as in the newer unaltered rocks.

I found very few dykes amongst these rocks of Ben Fyn, and none of any great importance.

The crystallization is in no way local, but affects the whole series equally; and it is that form so peculiarly characteristic of the older or pre-Cambrian rocks wherever they are exposed in this country.

The gneiss and other pre-Cambrian rocks in Anglesey, Caernarvonshire, and Pembrokeshire, especially the Dimetian or gneiss series, appear to be much in the same state of alteration; and the general petrological resemblance of the latter to some of these gneiss rocks of the Western Highlands will probably enable the two series to be correlated some day, or at least show that they belong to the same geological epoch or horizon in the history of our globe. These mountains of gneiss to the north of Auchnasheen attain a height of over 3000 feet, and are entirely devoid of any traces of the unaltered Silurian rocks found in Glyn Docherty, Glyn Laggan, &c.

The question as to how the Silurian rocks could have been brought into the positions indicated in the latter part of the section is a difficult one. Is it the result of a natural overlapping of the older rocks eastward by these newer rocks? or have they been brought into this position by faults? I saw no evidence of faults of sufficient magnitude to bring them to this position alone; but minor faults there are undoubtedly, and these have in some cases considerably altered the position of some of the beds. On the whole, however, the evidence seems to show that these Silurian beds have been deposited on the eroded edges of the lower gneiss rocks nearly in the positions in which they are now found, the present inclination of the beds being dependent upon subsequent movements, accompanied by some faults. These upper beds are undoubtedly made out of such materials as would be derived from rocks similar to those which now underlie them and to which they are unconformable; and hence it is that sometimes a superficial examination may possibly lead one to associate them. The persistent and equal metamorphism, the contorted character, and high N.W. strike of the lower series is so marked, however, that for any distance it seems almost impossible to confound them in any way with the comparatively undisturbed and unequally altered beds of the upper series, which also almost invariably strike in the opposite direction, or from N.E. to S.W., at a low angle of dip.

Putting aside the theoretical grounds which seem to me alone sufficiently conclusive, that Silurian beds could not by any force indicated here be converted into true gneiss and hornblende schists at one point and be left unaltered at a lower horizon, we have here, in my opinion, undoubted stratigraphical evidence which it seems to me impossible to refute or to account for in any other way than that of true discordancy by unconformity.

That Prof. Nicol and the older geologists were therefore right when they maintained that the Central Highlands contained and were largely made up of some of the oldest rocks in Scotland, there can, I think, be no doubt; but they have included with these rocks, according to my view, a series of sediments belonging to a far more recent period. On the other hand, Sir R. Murchison and Prof. Geikie, who were the first to point out the presence of some at least of these newer rocks, extended them into many regions occupied only by the older rocks.

Though I was unable to examine any of the other areas under dispute, I feel confident that the explanation offered in this section at Glyn Docherty will hold true in those also, and that the metamorphic rocks of the Central Highlands will all prove to be of pre-Cambrian date, the Cambrian and Silurian beds being contained in basins or depressions only formed by the older rocks, generally unaltered, and comparatively very limited in their distribution over those areas. The great metamorphic areas here, as in all other districts in Britain that I have been able to examine, are undoubtedly of pre-Cambrian date, and the changes which these rocks have undergone seem to have been seldom if ever repeated since to any important extent, whatever the forces at work at that time may have been.

Discussion.

Mr. De Rance asked whether the rocks of Ben Fyn were lithologically similar to those of the western country, and whether the former might not be intermediate in age. He doubted whether the curve shown in the section of the stratified rocks in Glyn Laggan could have been formed by the intrusion of granite there represented, and asked what had become of their prolongation.

Prof. Ramsay stated that he had been with Sir Roderick Murchison over the country with which this paper was mainly concerned, and had concurred with him in his view of the Lower Silurian age of the gneiss of the Central Highlands. He had never seen an unconformity such as was represented in the section on the wall, and did not see how the overlying rocks could have been deposited. The strata near Loch Maree he had not examined; others, however, in whom he had confidence, had done so; but he saw no reason, seeing how capricious metamorphic action was, why the Central Highlands should not be metamorphosed Lower Silurian. He even believed some of the granites themselves were only metamorphic. There is often no sudden break between a comparatively unmetamorphosed and a highly metamorphosed condition, but a gradual change. The Scotch surveyors, he believed, even hoped to be able ultimately to identify in detail the rocks of the Northern Highlands with the subdivisions of the Southern Uplands.

Dr. Hicks stated that his section was only meant as a rough diagrammatic one, but he would maintain its general accuracy. He showed that similar difficulties to those mentioned by Mr. De Rance existed even in Sir Roderick Murchison's section. The part which Prof. Ramsay had chiefly objected to, as he had explained in his paper, was obscure and probably faulted, and the section exaggerated the difficulties. That there was an unconformity was evident from sudden change in lithological characters and in the strike of the beds, which he could not otherwise explain. The great mass of rocks forming Ben Fyn could not be explained, as Prof. Ramsay appeared to think, by minor faults. If they were Lewisian, so must much of the Northern Highlands be.

49. *On the* Glacial Phenomena *of the* Long Island, *or* Outer Hebrides. Second Paper.

By James Geikie, LL.D., F.R.S., F.G.S., of H.M. Geological Survey. (Read May 8, 1878.)

[Plate XXXIII.]

Contents.

I. Introduction.

In a former paper* I gave some account of the glaciation of Lewis, the northern portion of the Long Island, and showed that the whole of that region had been rubbed and ground in a direction from south-east to north-west by land-ice which could only have come from the mainland. In the present paper I give some additional observations on Lewis, most of which were made during my first visit to the island, while others were noted upon a subsequent occasion, when I was accompanied by my colleague, Mr. R. Ethe-

* Quart. Journ. Geol. Soc. vol. xxix. p. 532.

ridge, jun. I also describe in detail the glacial phenomena of Harris and the other islands of the Outer Hebrides, which I traversed in the course of the past summer in company with my colleague, Mr. S. B. J. Skertchley. As all the islands have much in common from a glacialist's point of view, it is hardly necessary for my purpose that each should be described with equal detail. I have therefore selected Harris for more minute treatment than the others, as it may be considered typical of all; but as the evidence upon which my conclusions are based derives much of its strength from its cumulative character, it has not been possible to avoid giving a more or less particular account of each island visited.

II. Lewis * (Additional Notes).

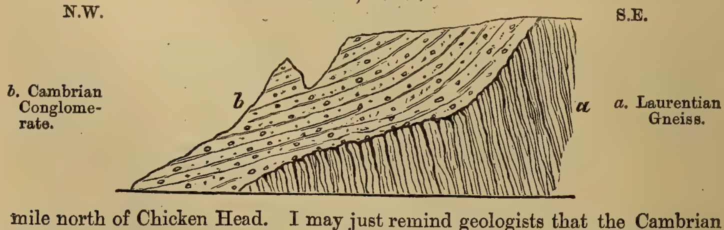
1. *Geological Structure.*—In my first paper descriptive of the Outer Hebrides I stated that although the gneiss of Lewis had a prevalent N.E. and S.W. strike, yet that direction was frequently changed. I ought to have mentioned that the N.E. and S.W. strike occurs chiefly in the east and central portions of Lewis. Thus it is well shown in the Eye Peninsula, where the gneiss, capped unconformably with Cambrian conglomerate, dips at a high angle to S.E.†

* For the spelling of place-names in Lewis I have in this and the preceding paper followed the maps of the Ordnance Survey. For the Gaelic orthography of the place-names in Harris and the islands to the south I am indebted to my friend Mr. Alex. Carmichael, of Creagorry, Benbecula. Mr. Carmichael has been good enough also to write out the words as they are pronounced. I have not thought it necessary, however, save in a few cases, to give the pronunciation along with the Gaelic word; but a few examples may be given here:—

Roinebhal,	pronounced	*Roineval.*
Langabhat	,,	*Langavat.*
Abhuinn	,,	*Auin.*
Rudh	,,	*Ru.*
Ceilegreihd	,,	*Keilegrey.*
Theorabhag	,,	*Theoravag.*
Aisgernis	,,	*Aiskernish.*

† Having been asked by several geologists whether I may not have been mistaken as to this dip, which is at right angles to that given by Murchison, I may state here that the bedding of the gneiss is extremely well seen in the coasts of the Eye Peninsula, and that there cannot be any doubt whatever about the dip, which is just as apparent as the dip of the overlying Cambrian strata, as will be seen in the annexed sketch, which represents a part of the coast-section half a

Fig. 1.—*Cambrian Conglomerate overlying Laurentian Gneiss, near Chicken Head, Lewis.*



mile north of Chicken Head. I may just remind geologists that the Cambrian strata occur only in the east of Lewis, and are restricted to a limited area in the neighbourhood of Stornoway.

The same strike continues west of Stornoway for a distance of eight miles or thereabout, and ranges over nearly all the area between Beinn Barabhais in the north and the river Laxay in the south. South-east dips also predominate near the Butt, the strike being approximately N.E. and S.W. as far south at least as Aird Dhail. In the mountainous district of the south-west, however, the strike is persistently N.W. and S.E., with a prevalent dip towards N.E. The same dip is also conspicuous over the Great Bernera, along all the sinuous coast-line of Loch Roag, in the neighbourhood of Barabhais &c. Throughout wide areas traces of bedding are often faint and deceptive, and frequently the gneiss appears to be quite amorphous. Crumpled and contorted stratification is of course a very common phenomenon. I give these additional notes on the dip and strike of the gneiss; for without an adequate knowledge of the "lie" of the rocks, it is hardly possible to realize the effect produced by glaciation on the contour of the ground.

2. *Direction of Glaciation in hilly Districts.*—In the paper already referred to mention has been made of the fact that, while ice-worn hummocks of rock abound in the low grounds of Lewis, it is yet rarely that glacial striæ appear upon them. In the hillier districts, however, ice-markings are much more frequently met with. Thus, in the district of Uig, which I visited in company with Mr. Etheridge, a number of well-striated rock-faces were noted, all of which pointed from S.E. to N.W.

The hill-slopes overlooking Loch Stacsabhat are not only distinctly glaciated from S.E. to N.W., but here and there the *roches moutonnées* are covered with striæ, more especially where the rock is close-grained and hard. Even in cases where the striæ have been effaced from the gneiss they may still be detected upon quartz-veins, which, being harder than the rock they traverse, usually project beyond its weathered surface.

We ascended Suainabhal (1300 feet) and found these appearances at many points along its steep flanks. This bleak hill, which stands comparatively isolated, is glaciated from base to summit, being in fact only a huge ice-worn hummock. It has been completely smothered in ice, and there are no contiguous high grounds from which that ice could have been derived. Looking from the top of the hill in what direction we may, we see nothing but a dreary, verdureless expanse of bare, grey, ice-worn hummocks, hills, and mountains, interspersed with innumerable lakes, and intersected by long straggling arms of the sea. The highest hills lie to the south-west, and even these appeared from our point of view to be glaciated very nearly up to their summits, which are between 1600 and 1700 feet in height. Not a few, however, showed steep cliff-faces, a feature which will be described in connexion with the glacial phenomena of North Harris. A narrow dark lake, some 2½ miles in length, that separates these sorely glaciated hills from Suainabhal, occupies a rock-basin which has evidently formed the path of a huge mass of ice that flowed north-west, the mountain-slopes on both sides of the lake being well glaciated. It is obvious therefore that the ice which overflowed Suainabhal did not come from the high grounds lying to the west and south, but from the south-east. In other words, it was not of local origin, but formed part of a general glacial covering that flowed in one determinate direction (S.E. to N.W.) across the whole breadth of Lewis; and we gain some idea of its thickness from the fact that no local glaciers which may have come from the mountains of North Harris were of sufficient extent to deflect it. It rose high upon the northern slopes of these mountains, and Suainabhal (1300 ft.) was simply overwhelmed, like a small boulder in the bed of a stream.

3. *Shelly Boulder-clays, &c.*—Along the sea-coast, near the Butt of Lewis, at Traigh Chrois, namely, and between that bay and the point called Sinntean, some excellent sections of Boulder-clay are exposed. Similar exposures also occur in the sea-cliffs of Traigh Chealagbhat, close to the Port of Ness. These sections were first noticed by Macculloch, whose description, however, is very meagre*. He speaks of the deposits as "alluvial matter," but does not attempt to account for their anomalous position, merely remarking that they seem to owe their origin to distant changes, on which he has "no other conjecture to offer than such as have been often produced to account for similar alluvia in various parts of the globe."

I have given a somewhat condensed account of these deposits elsewhere †, but describe them here a little more particularly, that glacialists may be able to compare them with similar deposits in other parts of Britain. The sections show a succession of three well-marked divisions, viz.:—

a. Lower shelly Boulder-clay.
b. Interglacial beds.
c. Upper shelly Boulder-clay.

But these are not always present in one and the same section. In some places the Lower Boulder-clay is wanting, and the interglacial beds vary much both in thickness and composition.

a. *Lower shelly Boulder-clay.*—This is a dark greyish-brown, sandy or earthy clay, which is usually tough, but when wetted becomes a soft unctuous silt. Although closely resembling similar deposits in the Lowlands of Scotland, it yet differs very markedly from the till which is commonly met with throughout Lewis and the islands of the Outer Hebrides generally. It is quite unstratified, but here and there contains irregular lenticular patches, veins, and beds of gravel, sand, and silt or clay. The included stones are generally blunted and subangular, and now and again show well-marked striæ. They vary in size from mere grit up to blocks several feet in diameter, and consist chiefly of gneissose rocks. But boulders of red sandstone, conglomerate, and quartz-rock, and liver-coloured quartz-pebbles, which have evidently come from the Cambrian conglomerates, occur somewhat numerously in places. Here

* 'Description of the Western Islands of Scotland,' vol. i. p. 189.
† 'Great Ice Age,' 2nd edit. p. 168.

and there, also, I noted fragments of quartz-porphyries, none of which could be identified as occurring *in situ* in Lewis. Scattered promiscuously through the matrix are many broken shells. A large number of these, owing to their fragmentary character, cannot be determined. Such fragments as were recognizable I handed to my friend Mr. Etheridge, who afterwards visited the sections with me, but we had unfortunately very little time to bestow upon a further search. A list of the fossils got by us is given by Mr. Etheridge in the 'Geological Magazine' for December 1876; they are only six in number, viz. *Truncatulina refulgens*, *Polystomella striato-punctata*, *Cyprina islandica*, *Astarte sulcata*, var. *elliptica*, *A. compressa*, var. *striata*, *Saxicava rugosa*. A careful search would, I have no doubt, add considerably to this list.

The upper surface of this Boulder-clay is generally very uneven, and is usually separated by a clear line of demarcation from the beds that immediately overlie it.

b. *Interglacial Beds.*—These consist of dark blue and grey, and sometimes brown laminated clay, silt, and mud, with sporadic stones, the lamination being occasionally very indistinct or absent, overlain by a series of stratified sand, gravel, and shingle, with here and there large boulders. This double set, however, does not always appear in one and the same section. In some places only the laminated clay, in others only the sand and gravel beds are present; or, again, both may be replaced by a sandy silt, with intercalations of sand, fine gravel, silt, and clay, and with stones not larger than one's fist sparsely scattered throughout. The two sets of beds often interosculate, but now and again the upper rests with a local unconformity upon the lower. But the general character of these deposits will be better gathered from the accompanying sketch sections and their explanations. Shells, sometimes whole, but usually in detached valves, occur throughout; they are mostly, however, mere fragments. The fossils we obtained are given by Mr. Etheridge in the paper already referred to, but it may be useful to mention them here. They are as follows:—

Triloculina oblonga.
Quinqueloculina seminulum.
Dentalina communis.
Truncatulina lobatula.
Polystomella crispa.
Nonionina asterizans.
—— depressula.
Balanus balanoides.
Salicornaria, sp.
Pecten islandicus.
Leda pernula.
Cardium echinatum.
—— edule.
Cyprina islandica.
Astarte sulcata.
—— compressa, var. striata.
—— depressa.
Tellina balthica.
Mactra solida.
Mya truncata.
Dentalium entalis.
Turritella terebra.
Natica Alderi.
—— Montacuti.
Aporrhaïs pes-pelecani.
Buccinum undatum.
Trophon truncatus.
Fusus gracilis.

c. *Upper shelly Boulder-clay.*—This is a reddish or brown sandy clay, which, like the lower mass, is unstratified. In some places it is dark greyish blue and more clayey, and often becomes very tough.

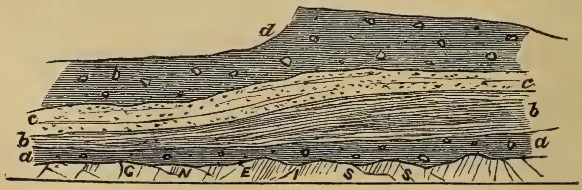
Its stones and boulders are of the usual shape, blunted and subangular, and occasionally show well-marked striæ. In size they vary up to blocks 4 or 5 feet across, and consist chiefly of gneiss; but fragments of red sandstone &c. also occur. They are often very irregularly disseminated through the matrix, in some places being pretty equally distributed, in other places gathering more closely together, so as to form now and then a pell-mell assemblage of stones and boulders, with only a meagre matrix of clay. Broken shells are sparsely disseminated throughout the matrix, appearing, however, to be nowhere so plentiful as in the Lower shelly Boulder-clay. They seem, indeed, to be quite absent from some of the exposures; for we searched the upper parts of the cliffs in several places without being able to detect a trace of any thing organic. A few fragments too small for determination were obtained at Port of Ness; but the only recognizable fragments came from the cliff-section at Traigh Shuainaboist: they were *Balanus balanoides*, *Cyprina islandica*, *Saxicava norvegica*, and *Turritella terebra*.

The Upper shelly Boulder-clay is generally separated from the underlying interglacial beds by a more or less well-defined line; there is often, indeed, a strongly marked unconformity between them, but occasionally the junction is much confused, and here and there the beds seem almost to pass into each other.

At Port of Ness a thick mass of coarse shingle, gravel, and sand caps the cliff, and appears to pass down into sandy boulder-beds, some stratified portions of which consist of shelly grit, gravel, and sand. These deposits overlie, and form probably a modified portion of the Upper Boulder-clay, into which they seem to pass.

The annexed sections (figs. 2–5) will further illustrate the appearances presented by the drift-deposits just described. The cliffs shown in the illustrations vary in height from 30 feet up to 70 or 80 feet.

Fig. 2.—*Cliff-section south of Traigh Chrois.*



a. Lower Boulder-clay, with a few broken shells, sandy, unstratified; stones subangular and blunted.

b. Brick-clay and silt, dark-blue and grey; sandy; a few sporadic stones; broken shells.

c. Stratified sand.

d. Upper Boulder-clay, brownish, unstratified; no shells seen here.

Depth of section about 70 feet.

In this and other figures the horizontal tint marking the Boulder-clay is not intended to represent lamination or bedding.

Fig. 3.—*Cliff-section: Sea-coast at mouth of Amhuinn Dhail.*

a. Angular *débris* of underlying gneiss, mixed with clay.
b. Dark-brown and blue clay, laminated, with fragments of shells and sporadic stones, smoothed and angular.
c. Gravel and sand, false-bedded.

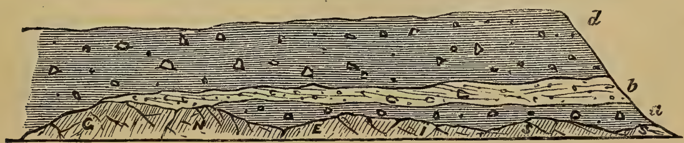
Depth of section about 45 feet.

Fig. 4.—*Cliff-section at Port of Ness.*

a. Lower Boulder-clay, with sandy patches; red sandstone and conglomerate boulders more common here than in other places.
b. Coarse shingle, gravel, and sand, containing here and there brick-clay, silt, &c.; rolled fragments of shells somewhat plentiful; very irregularly stratified beds.
d. Upper Boulder-clay, brown, sandy, unstratified, with a few fragments of shells.

Depth of section about 50 or 60 feet.

Fig. 5.—*Cliff-section at Port of Ness, east of section fig.* 4.



a. Lower Boulder-clay.
b. Coarse shingly sand and gravel, with rolled shell-fragments.
d. Upper Boulder-clay, sandy.

Depth of section about 50 or 60 feet.

In fig. 2 all the beds are shown. Fine sections, exhibiting the two Boulder-clays, with the Interglacial beds, are well seen in the cliffs at Traigh Chrois; some of these show the Upper Boulder-clay cutting down, as it were, into the stratified beds; while others, in like manner, indicate how the Lower Boulder-clay has been worn and denuded before the deposition of the Interglacial sands and clays. These and other appearances, however, are represented in several sketch sections which have already been published*, and need not be further described here.

* *Op. cit.* p. 169.

In fig. 3 only the Interglacial beds appear; but the coarse angular *débris* which underlies the laminated clay is probably the representative of the Lower shelly Boulder-clay.

In figs. 4 and 5 the Interglacial beds, which can usually be divided into a lower clayey and an upper sandy series, are represented by the beds marked *b*. At the Port of Ness they are exceedingly coarse, rudely bedded, and charged with many large angular boulders. In these respects they contrast somewhat strongly with their equivalents on the other side of the island.

With the exception of a brick-clay that occurs in the Eye Peninsula, the deposits now described are the only shelly beds of glacial age that I have met with in the Outer Hebrides. They are nowhere seen in contact with the unfossiliferous bottom-till that forms the main drift of Lewis; and thus their relative position in the glacial series can only be inferred from other evidence, to be stated in the sequel. They do not seem to reach more than 100 feet above the sea, but form a narrow belt of low ground that extends from the Port of Ness across the island to the west coast between the mouth of the Amhuinn Dhail and Sinntean.

The Lower shelly Boulder-clay betrays no mark of aqueous origin, but resembles in every respect a deposit that has been formed by the direct action of glacier-ice. The broken shells that are scattered through it show that the ice, underneath which it was rolled forward, overflowed from what had previously been the sea-bottom; and the presence of many boulders of Cambrian rocks in the clay indicates a movement from the east or south-east.

The interglacial deposits point to a recession of the ice, during which the Lower shelly Boulder-clay was much denuded. At this time the sea overflowed the northern extremity of Lewis; but the extreme coarseness of the shingle beds at the Port of Ness would seem to indicate that the submergence was very limited. The laminated clay beds, however, were probably deposited in somewhat deeper water, the overlying coarser beds pointing to the gradual retreat of the sea or reelevation of the land.

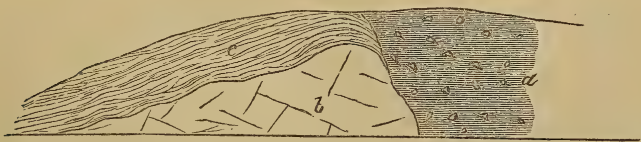
The Upper shelly Boulder-clay precisely resembles the Lower in its origin. It points to the presence of glacier-ice that overflowed from the bed of the Minch upon the low ground near the Butt, ploughing into the preexisting drifts, confusing the bedding, and here and there tumbling the strata up and incorporating them with its bottom-moraine.

Shelly Brick-clay.—At Garrabost, in the Eye Peninsula, there is a dark greyish-blue clay, worked for brick-making. It appears to be for the most part quite homogeneous, and shows little or no trace of lamination. Here and there I picked out of it small fragments of shells, none of which were recognizable. The relation of this clay to the till of the neighbourhood was not apparent at the time of my visit (1872); but I have since learned from the owner, Mr. Henry Caunter, some further details, which prove the clay to be of interglacial age, as I had all along suspected. It was overlain, when I saw it, by sand, like the interglacial silt beds near the Butt, and had evidently been ploughed out by other than mere aqueous erosion. The sand and clay together formed low hummocks or hillocks, rising only a few feet over the general surface of the ground.

Mr. Caunter informs me that the clay has been got as thick as 16 feet, and does not show any trace of bedding as a rule. It is generally, he says, very compact and solid, with sometimes a seam or two of sandy clay. No large boulders occur in it, but now and again small stones and a few shells are met with. At one place the clay was overlain by a bed of well-laminated clay, in which sea-weed, "like a mass of the common tangle," was found. "The tangle," Mr. Caunter writes me, "stood erect as high as 6 feet, and extended over a length of 13 feet and a breadth of 7 feet. It appeared to have grown on the solid unstratified brick-clay, and to have been subsequently buried in the successive layers of muddy material which now form the overlying stratum of laminated clay." Sometimes the clay rests directly on the Cambrian conglomerate, at other times it is underlain by blue till or boulder-clay, or, as the case may be, by shelly sand, like an old beach-deposit. It is overlain by a considerable depth of fine sand in some places.

The clay, Mr. Caunter remarks, has "the appearance of having been ploughed or scored out, and bears evident marks of having been subjected to great pressure and force," red till reclining against and upon it, as exhibited in the annexed illustration (fig. 6), which shows a section exposed at the brickworks during the course of 1876.

Fig. 6.—*Section at Brick-works, Garrabost, Lewis. By Mr. H. Caunter.*



a. Red Till. *b.* Amorphous brick-clay.
c. Stratified brick-clay, with sea-weed.

Brownish sand, with no shells, which is most probably of late glacial age, sometimes overlies all the glacial deposits, and goes up to a height of 200 feet.

The beds now described occur at a height of 175 feet above the sea, and are in all probability of the same, or approximately the same, age as the similar beds in the north of the island.

Some twenty years ago Dr. Davy (brother of Sir Humphry Davy) took a collection of shells from the Garrabost clay to the Museum in Jermyn Street for determination; and Mr. Caunter informs me the fossils were decided at that time to be of glacial age. Unfortunately I have not been able to trace the whereabouts of this collection; for there is no record of the shells in the books at Jermyn Street, and, as Mr. Etheridge tells me, not a single specimen from any glacial deposit north of the Kyles of Bute occurs in the Museum. Mr.

Caunter, however, had in the course of time made another collection of shells, which he showed to Dr. Carpenter and Professor Wyville Thomson when they visited Lewis some years ago. He was then informed that the shells were all of recent species, still found living round the shores of Lewis, which of course might quite well be the case, and yet at the same time the shells might be of interglacial or late glacial age. Not knowing this, but judging the shells to be no longer of any scientific value, Mr. Caunter unfortunately threw them away. He has, however, been good enough to supply me with a number of specimens of the clay and its associated deposits, which have been carefully washed by Mr. James Bennie, with the result of yielding a number of Foraminifera and Entomostraca. These, however, will be described in a future paper, when I hope to conclude my observations on the glacial phenomena of the Long Island.

It ought to be mentioned that occasional loose boulders of hard Cambrian grit and sandstone are met with in the Eye Peninsula, which are of precisely the same character as the similar boulders of the same rocks that occur in the west of Lewis, at Barabhais, and in the neighbourhood of the Butt. These can hardly have been derived from any part of the Cambrian strata which are now exposed in the neighbourhood of Stornoway. The latter are composed of conglomerate and somewhat incoherent grit and shaly sandstone, which is soft and crumbling. The erratics, however, are exceedingly hard; and I agree with Mr. Caunter that they have in all probability been derived from the Cambrian of the mainland, as at Ullapool.

III. Harris.

1. *Physical Features.*—Harris, which with Lewis forms one island, is about 20 miles in length, and, like most of the islands of the Outer Hebrides, has a most irregular coast-line. It attains its greatest breadth (18 miles) between Loch Resort and Scalpa Sound, and narrows at Tairbeart (Tarbert) to such an extent that the east and west lochs of that name nearly meet, the distance between them not being more than half a mile. South of the Tarbert the island attains an average breadth of 7 miles or so. Harris is almost wholly mountainous, the only level land consisting of a few insignificant patches of alluvium and raised beach. In North Harris occur some of the boldest mountains in the Long Island, among which some of the most prominent are An Cliseam (the Clisham), 2622 feet; An Langa, 2438 feet; and Leoisabhal, 1351 feet.

The hills of South Harris do not reach an elevation of 1700 feet, the highest points being An Tarcul (1654 feet) and Beinn Losgcinntir (1529 feet) in the north, and Roinebhal (1506 feet) in the south.

The barren aspect presented by the hillier portions of Lewis is repeated over all Harris. The whole country looks as if it had been scraped and bared, any soil it may once have possessed having been swept off the hill-tops and hill-sides, and only a thin sprinkling left in valleys and sheltered hollows. In North Harris and the northern part of South Harris the mountains often show precipitous faces to the north-east, a feature which is wanting in the southern districts.

The general outline of the high grounds, as viewed from east and south-east, is hummocky, rounded, and somewhat monotonous. This character prevails over all Harris. There is a singular absence of peaks and serrated ridges, the only appearance of such occurring at the highest elevations, as in the Langa and the Cliseam. Seen from the south-west of Lewis the Harris hills assume a much wilder and more rugged aspect; and even from any eminence in Harris itself the rounded and flowing outline of the ground, which appears so conspicuous when the observer looks towards north-west, becomes much less striking when his face is turned in the opposite direction.

There are a number of deep glens in Harris; but, as might have been expected, the streams are of little importance. In many of these valleys lakes occur, the most notable being Loch Lacasdail (Laxdail). Like most mountain-lakes they are long and narrow, and relatively deep. Besides these mountain-lakes there are numerous small lakes or tarns, that lie in rocky hollows. These are specially abundant in the rugged rocky low country of South Harris that slopes down to the shores of the Minch. The largest of the lakes is Loch Langabhat, which is two miles long by about half a mile in breadth. Most of the others are much more insignificant.

2. *Geological Structure.*—To Macculloch's account of the petrology of Harris I have little to add. There is, as usual throughout these islands, much sameness in the rocks, which consist almost exclusively of gneiss and its varieties. There are, however, certain of these varieties which appear to be confined to special localities; thus the beautiful granatiferous gneiss of Roinebhal seems to be peculiar in Harris to that mountain, although somewhat similar granatiferous rocks are met with in some of the islands further south. Numerous dykes and veins of basalt traverse the country, the larger dykes having a tendency to keep along the strike of the gneiss. The basalt is generally dark grey or blue, with a texture varying from granular to crypto-crystalline and compact. It generally weathers with a brown ferruginous crust, and here and there splits up into rough flags which have often a minute fissile structure, so much so as in places to assume quite the aspect of a decomposed ferruginous shale.

The strike of the gneiss throughout Harris is approximately north-west and south-east, with occasional local deflections. In North Harris the average strike is W. 15° N. to E. 15° S., with a somewhat constant dip towards the south-west; and hence all the great escarpments face the north-east. The same dip and strike continue into South Harris as far south as Borgh. In the neighbourhood of Miabhag (Forest of Harris) very low dips are found (10° to 15°); but the inclination increases in the area between Airdasaig and Loch Seaforth to 35°, 50°, and upwards, the beds not unfrequently becoming vertical. In the north part of South Harris the strike swings round to W. 30° N. and E. 30° S., the dip being, as before, south-westerly, at angles that vary from 20° up to nearly vertical. South of Borgh the strike is W. 35° N. and E. 35° S, and the dip north-east, usually at high angles. In the neighbourhood of Roinebhal, Loch Langabhat, and the rocky district to the north-east the strike is approximately the same and the beds vertical; but stratification is frequently obscure. These dips show that there is at least one main anticlinal between the south-west mountain-district of Lewis and North Harris; and they likewise indicate the presence of one main synclinal axis traversing the island from Borgh Bay to Fionnsbhag (Finnsbay). The main dips are shown by black arrows on the accompanying map.

3. *Glaciation.*—Mr. J. F. Campbell describes* the hills of Harris as being "much glaciated, but weathered;" and he adds, "So far as I could make out, the ice came from N.N.W. through a gorge at Tarbert." It needs but a glance to assure one that glacier-ice has modified almost every part of the surface of Harris. The hill-sides are everywhere mamillated and rounded, and crowded with *roches moutonneés*, while the tops of most of even the highest hills are smoothed off. A closer and more detailed examination convinced my companion and myself that not only are the marks of glaciation general over all Harris, but also that the direction in which the abrading agent flowed has been from south-east to north-west, or in approximately the same line as the general or average strike of the gneiss. In certain of the higher valleys, however, there are distinct traces of a later local glaciation, to which reference will be made in the sequel. Meanwhile, some details of the main glaciation fall to be given here.

Perhaps one of the best displays of an ice-worn surface occurs in the immediate vicinity of the Tarbert. All the hill-slopes in that neighbourhood are finely glaciated. This is particularly the case with the hill called Gilebhal-ghlas (1556 feet), which presents a broad undulating surface to the south, thickly set with dome-shaped and finely mamillated rocks. Upon not a few of these rounded masses, glacial striæ are still preserved (in most cases they are faintly marked), all pointing persistently towards north-west, and indicating the ice-flow to have been from the south-east. Striæ occur also at various places near the shore and close to the road leading from Tarbert along the base of Gilebhal-ghlas. The hill-slopes on the opposite coast of West Loch Tarbert are also highly glaciated in the same direction.

Above the village of Airdasaig the road to Stornoway passes the base of a steep cliff that faces the north-west, and forms the westerly termination of Gilebhal-ghlas. Had the land been glaciated from the Atlantic, this cliff-face must have been highly abraded and ice-worn; for it would lie right in the path of any ice advancing from the sea. It shows, however, very little trace of rubbing; and this is just what we should expect, for it occupies the *Lee-seite*, and has thus escaped the action of the glacier ice that so polished the flanks of the mountains in its neighbourhood.

The direction of the glaciation is also well seen upon the moun-

* Quart. Journ. Geol. Soc. vol. xxix. p. 545.

tain-slopes that extend along the whole northern shore of West Loch Tarbert. Throughout that region *roches moutonnées* and striæ plainly indicate a movement from the south-east, the average direction being from E. 20° S. to W. 20° N. We traced the glaciation in this part of Harris up to a height of 1600 feet on the shoulders of the Cliseam and the Langa, the two highest hills in the island. These heights were obtained by aneroid measurement, corrected by reference to Ordnance Survey data, which were kindly supplied to me by the late Major-General Cameron, C.B., Director of the Survey. Above the level of 1600 feet there is no trace of any glaciated surface or outline; on the contrary, the rocks are excessively scarred, shattered, and weather-worn, some of the hill-tops being ridged and peaked. The line of demarcation between the non-glaciated rock above and the smoothed and *moutonnée* surface below is well marked, but is of course most conspicuous when viewed from a distance, when the eye can take in the whole mountain-mass from summit to base. Nothing, indeed, can be more striking than the contrast between the two rock-features when viewed under such conditions. Rounded, dome-shaped rocks, bald, grey, and sometimes almost white, cluster upon all the slopes, especially on spurs and prominences facing the south-east, and sweep up and over hill-tops which are under 1600 feet in height. Above that height, however, they do not extend, and the horizontal line that marks their upper limits seems, from a distance, as straight as if drawn with a ruler. Beyond this line the rocks are craggy, irregular, and broken; they show no smooth faces to reflect the light, and look much darker, therefore, than the grey masses below.

Roches moutonnées are frequently ruinous, of course, as well at low as at high elevations; for much depends on the character of the rock and the form of the ground. In general, however, mamillated surfaces occur in best preservation at the lower levels; and this is as one would expect, for the rocks at the upper limits of the ice-sheet would be earlier exposed to the action of frost, and might, in many cases, become broken up before the glaciers had melted away from the valleys. Nor can it be doubted that even now the action of frost is, as a rule, more destructive at the higher than the lower levels of the land. Here and there the signs of former glaciation are passing more or less rapidly away. This is conspicuously the case upon such cliff-faces as those that occur in Gleann Sgaodail, Bealach na Ciste, and Bealach Miabhag, where, owing to the steepness of the cliffs and the abundant jointing of the gneiss, frost is enabled to rupture and shatter the rocks, and to shower their *débris* upon the lesser slopes below.

I have said that the average direction of the glacial striæ along the northern shores of West Loch Tarbert is from E. 20° S. to W. 20° N. This direction holds good throughout all the grey mamillated hills and hill-slopes that undulate upwards to the shoulders of the Langa and the Cliseam. Here and there, owing to the uneven surface of the ground, there are slight deflections of the striæ; but such are quite local, the general trend of striæ and *roches mou-*

tonnées being very persistent, notwithstanding the rugged configuration of the ground. On the north side of the Cliseam, however, the glaciation trends rather more to the north, the average direction over the area that extends eastwards to the shores of Loch Seaforth being from S. 32° E. to N. 32° W., a direction that coincides with that of the glaciation in the adjacent districts of Lewis.

In short, an examination of the *roches moutonnées* and striæ in North Harris leads irresistibly to the conviction that the whole of that country has been smothered in a sheet of ice, the surface of which attained an elevation of not less than 1600 feet above what is now the sea-level. It is further certain that that ice-sheet moved across the land from south-east to north-west, ignoring the minor undulations of the ground, but being to some extent deflected by the great masses of the Cliseam and the Langa, the summits of which rose above the surface of the *mer de glace.* In the bottoms of several of the valleys of North Harris that intersect the general direction of glaciation, striæ and *roches moutonnées* afford indications of the ice having been slightly deflected by the contour of the ground, and similar minor deflections may be observed upon steep hill-slopes that face the south-east. As examples, I may point to the glaciated rocks in Gleann Abhuinn-eadar and in Bealach na Ciste, and to the fine display of *roches moutonnées* between the Tarbert and Loch Lacasdail.

South Harris is not less well glaciated than the area just described. Indeed it is even more so; for while the tops of several of the highest mountains in North Harris have never been overflowed by ice, there is but one point in the southern part of the island which seems to have escaped the grind of glacier-ice. The point referred to is the dominant part of the high ground between West Loch Tarbert and Traigh Losgcinntir, which reaches an elevation in the Tarcul of 1654 feet. With the exception of this insignificant area, all the ground lying between West Loch Tarbert and the Abhuinn Lacasdail is highly glaciated, the *roches moutonnées* on the East Stoc-cleit and the hills overlooking Traigh Losgcinntir being especially noteworthy. In the neighbourhood of East and West Lochs Tarbert the average direction of the striæ in South Harris is about E. 20° S. to W. 20° N.; but as the valley of the river Lacasdail is approached they take on a little more northing, the average being as near as may be W. 30° N.

The *roches moutonnées* in the district lying between Miabhaig and Greosbhag are smoothed off in the same direction, the striæ occasionally pointing to N. 40° W. Conspicuous *roches moutonnées* occur in the valley of the river Lacasdail, those in the vicinity of the lake being very well marked. Finely glaciated faces may also be observed again and again along the whole way between the mouth of the river Lacasdail and Scarrasta, the striæ having an average trend of W. 30° N. Indeed all the hills along the west coast bear evident marks of having been smothered under glacier-ice; they are abundantly rounded, and, notwithstanding the weathering which the *roches moutonnées* have experienced, striæ are yet occasionally well preserved. On the northern slopes of Carran and on Beinn Sheileboist the direction of these is W. 30° N.; on the slopes of Cleite Niseboist it is W. 28° N.; near Borgh Meadhonach it is W. 35°–40° N.; a little south of Borgh-mor it increases to N.W.; and in one place, halfway between Borgh-mor and Scarrasta, the trend is N. 15° W. This latter, however, is quite local; for on the hills immediately south of Scarrasta the glaciation has the normal direction of W. 30° N.

After leaving the Northside Sands the road to Obbe passes through ruinous *roches moutonnées* and hummocks of gneiss. Greabhal, the rocky hill immediately to the north, being fully exposed to south-east and south-west, has been subjected to much abrasion. We did not detect any striæ, however; but the trend of the *roches moutonnées* and smoothed faces of rock is unmistakably from south-east to north-west.

Roinebhal (1506 feet), the most conspicuous hill in the south of Harris, is smoothed from base to summit; but, owing to the weathering of the gneiss, few striated faces have been preserved. We noted striæ, however, on the south-west slope of the hill at the height of 950 feet or thereabout, and they pointed to W. 30° N. At the summit the rock, which consists of highly hornblendic and granatiferous gneiss, traversed by basalt dykes, is broken up by frost &c., and the *roches moutonnées* are hardly recognizable. But, notwithstanding this, one cannot fail to see that the whole contour of the summit, which has a rounded and smoothed-off appearance, differs markedly from the configuration of those rugged mountain-tops that rise to a greater elevation than 1600 feet, as, for example, the Langa and the Cliseam in North Harris, and Hecla and Beinn-mhor in South Uist. Some little distance down from the top of Roinebhal, the *roches moutonnées*, although broken up, are yet recognizable. While, doubtless, the ruinous aspect of the rounded rocks and the obscurely or faintly marked character of the glaciation at the higher elevations is in large measure due, as before remarked, to the early exposure of the hill-tops to the action of frost, yet we may well believe that the glaciation was never so intense there as at lower levels. A hill-top over which a thickness of 50 or 100 feet of glacier-ice flowed would, other things being equal, be less deeply ground and abraded and fluted than a hill-slope exposed to the pressure of upwards of 1000 feet of ice. Hence we might well expect to find the marks of glaciation at heights of 1500 or 1600 feet much more evanescent than at lower levels.

The country immediately to the north of Roinebhal is low-lying, and rises with a somewhat gentle inclination until it abuts upon the hills that trend along the west coast of the island. It is impossible to convey an adequate impression of the barren and desolate aspect of this part of Harris. The ground is rough and rapidly undulating and all but destitute of vegetation, what little grass there is finding a soil for itself only in cracks and crannies of *roches moutonnées*, which are otherwise so bare and fresh-looking that it needs but little imagination to conjure back the old ice-sheet. Every thing glacial looks as perfect as if the Ice Age had but recently passed away. But although the dome-shaped rocks have so fresh an appearance, striated faces do not frequently occur. The *roches moutonnées* are all more or less weathered, and the fine marks left by the ice-plough have often been entirely obliterated. Now and again, however, on bosses of more durable varieties of gneiss, striæ may be detected. We found a number to the east of Loch Langabhat, which varied in direction from W. 35° N. to W. 40° N. Between Loch Langhabhat and Cnoc a Ghobha the hills are smoothly rounded and pretty well clothed with grass, recalling the green slopes of the Silurian Uplands of Peeblesshire. We got no striæ on these hills, but at their base, on exposed rocks about half a mile from Loch Langabhat, found them pointing W. 35° N. On the hills overlooking Loch na Morcha from the east, a number of striated rocks are seen, the direction of glaciation varying from W. 30° N. to W. 35° N. The same trend is found upon the rocks in the vicinity of Obbe and on the seaward slopes of Straundabhal in the district of Rodal.

All the mountains of Harris are fluted on the large scale, the rounded ridges and intervening hollows running in the direction of the strike of the gneiss, and being most conspicuous when the latter coincides with the trend of glaciation. This fluted appearance is perhaps most noticeable on hill-slopes that face an open valley or a sound of the sea. Thus along both shores of West Loch Tarbert it is well seen. The mountains that rise south and north of the river Lacasdail are also well fluted ; and an excellent example of the same phenomenon is afforded by the hills that face the Sound of Harris between Rudh-Reinis and Rudh-Charnain. This fluting is evidently due to the unequal yielding of the gneissic strata ; and although its origin probably dates back to preglacial times, there can be no doubt that much of it is due to glaciation ; for it is when the line of strike corresponds with the trend of the ice-flow that the fluting is most marked. When the strike and the glaciation do not so agree in direction the fluting becomes less obvious, and often wholly disappears.

We did not land upon any of the islets in East Loch Tarbert, but we touched at Scalpa twice, and had a good opportunity of seeing its configuration and that of the other islets in its vicinity. It has clearly been glaciated all over, and the same has been the case with Taranseidh and Scarpa off the west coast of Harris.

In fine, the glaciation of Harris is so clearly marked that no further evidence of till or erratics is needed to show that the whole land has been abraded by glacier-ice coming from the south-east. Even the highest mountains, as we have seen, have been striated horizontally along their flanks by ice that streamed against them on its way out to the Atlantic. As one might have expected, the striæ are frequently deflected ; for the bottom of the ice-stream would naturally accommodate itself to the surface over which it flowed. Such local deflections, however, were not propagated to the upper strata of the ice, as is shown by the persistent direction of the striæ and *roches moutonnées* on hill-tops and exposed places. Nevertheless there can be no doubt that the mountains of North Harris did deflect the whole mass of the ice-sheet, as is proved by the changes in the direction of the glaciation to the north and south of the Langa and the Cliseam. These appearances, however, are best seen upon the map (Plate XXXIII.). Unfortunately, owing to the small scale, I have not been able to indicate all the bearings taken by us.

4. *Till or Boulder-clay.*—The till of Harris presents, I need hardly say, the same general character as the bottom-till of Lewis. It may be described as an amorphous gritty and sandy greyish clay, more or less abundantly charged with angular, subangular, rounded, and, now and then, well-striated stones*. Sometimes, however, it assumes the character of a tough dark-blue clay, with angular and subangular stones and boulders; in other places it contains masses of laminated clay, silt, and sand, and, now and again, itself shows a kind of rude bedding or, rather, arrangement of stones and boulders; while in yet other places it passes into a rough pell-mell morainic *débris*, made up of earth, clay, grit, angular gravel, and large and small blocks of gneiss, many of which show traces of glacial abrasion.

If the glaciation of the rocks of Harris indicates clearly the direction from which the ice overflowed Harris, we shall find the evidence supplied by the old *moraine profonde* of that ice no less decisive on this point; for, whether we have regard to the distribution of the till, to its peculiar position, to the mode in which it has been, in many places, gradually accumulated, or to the proofs of transport in one determinate direction which its included boulders supply, we shall be alike forced to conclude that the movement was from south-east to north-west.

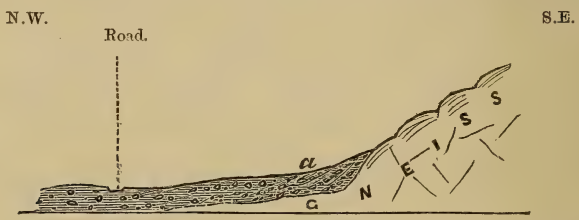
The till nowhere forms such a broad and thick enveloping sheet as the massive deposit that cloaks the Lowlands of central Scotland. On the contrary, it is exceedingly patchy, resting for the most part in valleys or on gentle declivities, and seldom reaching a greater thickness than a dozen feet or so. But although it is so sparsely developed, it nevertheless gathers in some bulk and spreads over considerable areas along the western borders of South Harris. Hardly a trace of it, however, is met with throughout the rough undulating tract of bare grey rock that extends inland from the east coast until it merges with the hills that overlook the western shores of the island. This, of course, is what we might have anticipated; the till has gathered thickly in those places where it would be protected from the full grinding of the ice. This is well seen at Clife Sheileboist, along the shores of Traigh Siar, at Scarrasta, and along

* I have explained in my former paper why the stones in the till of a gneissic region do not show striæ so frequently as the stones in the till of the Lowlands. Gneiss, as a rule, is not well adapted to receive and retain striæ; it is too granular and coarse, and it is generally only the harder and finer-grained varieties that show striation. Nevertheless the proportion of stones which have been subjected to much abrasion is not less than in the till of many upland tracts in central Scotland. The well-known blunted and subangular form is always plentifully present.

both shores of Traigh an Taobh-tuath. Between Borgh and Maodal the till lies close in at the foot of the cliffs and precipices, and spreads out seawards in low sloping ground. Similar appearances recur on the opposite side of the bay; the whole of this area, in short, seems, during the glaciation of Harris, to have formed a sheltered recess, in which the till was allowed to accumulate to a greater extent than elsewhere. No such continuous deposits of till occur in North Harris; but patches are common enough, and these are almost invariably met with either in valleys that coincide in direction with the primary glaciation, or sheltering on the *Lee-seite* of *roches moutonnées* whose smooth faces look towards the south-east. The fact that the till is so frequently found lying in considerable thickness in the rear of prominent rocks, the *Stoss-seite* of which faces the direction whence the ice flowed, is sufficiently suggestive, and may be observed in every part of the island.

An examination of the till in such sheltered positions points even more strongly to an ice-flow from the south-east. Thus at Clife Sheileboist (Fig. 7) the till that shelters on the north-west side of the hill shows a kind of rude arrangement of its stones and boulders, which are inclined outwards and downwards from the rock against which the deposit abuts. Similar appearances show themselves in

Fig. 7.—*Section of Till near Clife Sheileboist, South Harris.*



a. Till, showing rudely bedded arrangement of stones in lee of rock.

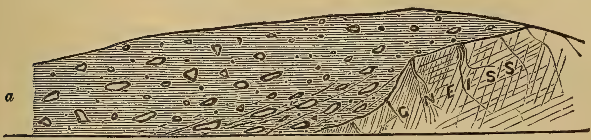
many other places along this part of the sea-coast; and they may also be studied to great advantage in the numerous openings on the side of the road leading from the Tarbert to Fincastle (Fig. 8). The phenomenon is well known on the mainland of Scotland, and has been described by me elsewhere*. It shows how the till was gradually piled up on the lee-side of rocks and hills, much in the same way as *detritus* gathers behind a boulder in the bed of a stream.

Although the rocks of Harris consist for the most part of gneiss, and it is usually quite impossible to say how far any isolated boulder may have travelled, yet we may often detect in one and the same section of till and gneiss certain boulders and the parent rock from which these have been derived. In every case of this kind that came under our observation the stones invariably lay to the west or north-west of their parent rock. The truncated ends of the gneiss were bruised and bent over towards the north-west, and the frag-

* 'Great Ice Age,' 2nd edit. p. 18.

Fig. 8.—*Section of Till, Fincastle Road, North Harris.*

N.W. S.E.



a. Till, showing rude arrangement of stones in lee of rock.
Depth of section 12 or 15 feet.

ments dislodged from them and enclosed in the superincumbent till streamed away in the same direction. A good example of this is shown in the annexed sketch section (Fig. 9), taken from a pit on the

Fig. 9.—*Section of Till, Fincastle Road, North Harris.*

N.W. S.E.

a. Till; *v*. Vein of felspar rock in gneiss, fragments of which are seen lying to north-west, enclosed in till at *v v v*.
Depth of section about 10 or 12 feet.

side of the Fincastle Road. A similar well-marked example occurs close to the landing-stage at the Tarbert, where the *débris* derived from a vein of pink felspar-rock and beds of dark hornblendic gneiss and schist are seen enclosed in the drift and streaming away from the parent rocks in a westerly direction. Of course, in very many places, the gneiss shows a firm and glaciated surface under the till, and in such cases we do not expect to meet with the appearances just described.

The only rock-fragment in the till which I took to be probably a stranger to the island was a hard blue calcareous greywacke or siliceous limestone. No rock of this kind, as far as I know, occurs in the Long Island, but it closely resembles some of the impure limestones or calcareous greywackes associated with the Silurian limestones of the Northern Highlands. A limestone occurs at Obbe, in Harris; but the boulder referred to bears no resemblance to it. I detected it in a pit on the Fincastle Road. Stones foreign to the island appear to be so entirely wanting in all the other exposures of till *

* Of course it is quite possible that some of the till stones may have been derived either from the bottom of the Minch or from the mainland. One meets with occasional fragments of syenite, boulders of basalt are not very uncommon, and some of these may not belong to Harris; but as basalt-dykes occur in the island, and the gneiss is occasionally syenitic, we cannot cite these boulders as strangers.

examined by me, that the occurrence of this solitary stranger, if it really be one, is interesting.

Many appearances which are familiar features in the till of the Lowlands characterize the till where it occurs in greatest mass along the west coast of South Harris. At Traigh Siar, for example, we have an excellent section, showing the occurrence of bedding in the till. The deposit at this place is a dark grey clay, very tough and full of grit, with stones sparsely scattered through it. Enclosed in this till are irregular lenticular beds of laminated clay and fine sand, with lines of water-worn gravel, and sporadic angular and subangular boulders. In places these bedded deposits become very stony, shading off into, and becoming confusedly mixed up with, the till. The stones in the till, I should mention, are usually subangular and blunted, and occasionally striated. Lines of stones may also be traced in the till. All the beds evidently form part and parcel of one and the same deposit, the rounded stones and gravel and bedded portions pointing to the action of subglacial waters, and being generally of the same nature and origin as the similar intercalations in the till of Switzerland. The whole rests upon a glaciated surface of highly contorted gneiss.

5. *Erratics.*—Next to the *roches moutonnées* of Harris, the most conspicuous objects from a glacialist's point of view are the erratics and perched blocks. These are common enough in most parts of Harris, but they certainly occur in greatest abundance in North Harris, some of the mountain-slopes being sprinkled with them in myriads. They are of all sizes, from less than a foot across to blocks measuring 20 feet and more in diameter. Most of the larger ones and a large proportion of the smaller ones show no trace of glacial abrasion, but are just such loose angular and weathered blocks as are launched upon the sides of an Alpine glacier. Not unfrequently, however, the boulders gave some evidence of glacial grinding and smoothing, although, so far as I saw, none had preserved any striæ. They are scattered promiscuously over the ground, some dotting hill-tops, others crowding upon hill-slopes and valley-bottoms. Sometimes they rest on till, at other times they are perched on hummocky moraines and *roches moutonnées.*

Nearly all are composed of gneiss or gneissic rocks, and have evidently travelled no great distance. Indeed, in many cases, they are quite local, the erratics at the lower end of a valley having come from the hills drained by it. Amongst erratics which may be exceptions are certain large boulders of a blue calcareous greywacke or impure limestone, which I saw on the lower slopes of the Cliseam, overlooking the road to Stornoway. I have seen no rock like this *in place* in any part of the Outer Hebrides; yet it is quite possible that the erratics may be derived from some unknown mass or bed of limestone in the hilly region lying east of Loch Seaforth. Here and there, both in North and South Harris, I met with large boulders of a syenite strongly resembling some of the syenite of Skye; but as the gneiss of Harris now and again assumes a syenitic aspect, I have but little doubt that the boulders referred to are of local origin. Of the same nature are erratics of hornblende-rock, of mica-rock (a rock composed almost exclusively of brown mica, with a very little felspar), and of many other peculiar varieties, all of which, however, I have seen in place, interstratified with and passing into the common basement-rock of these islands. Besides these, we occasionally come upon boulders of basalt of much the same character as the basalts of Skye; but since dykes of this rock are common in Harris and in the islands of the Outer Hebrides generally, it is not necessary to suppose that these have been derived from other than local sources.

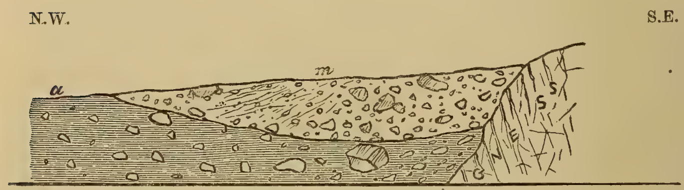
6. *Morainic débris and Moraines.*—Morainic *débris* and well-marked hummocky moraines are of very common occurrence, especially in North Harris and the contiguous mountain-districts of Lewis. In South Harris they are less conspicuous, and much of what might be taken there for morainic *débris* is simply coarse till. Morainic mounds are scattered about the hill-sides in the neighbourhood of the Tarbert, and they are also commonly met with in all the glens that descend from considerable elevations in North Harris. Thus, in the valley occupied by Loch Lacasdail, well-marked moraines run along both sides of the lake up to the height of 100 feet at least above its surface. Small moraines are also conspicuous in the short deep glens that open upon Loch Lacasdail. The glaciated hills that face West Loch Tarbert from south and north have their lower slopes thickly sprinkled with morainic mounds, the moraines being crowded together upon the low ground through which the road from the Tarbert to Stornoway passes. On the opposite side of the loch, similar mounds are equally abundant. Some excellent examples of moraines also occur at the mouth of Gleann Sgaodail and in all the glens that come down from the Langa and the Cliseam. The Bealach na Ciste likewise abounds in morainic *débris* and hummocky moraines, fine examples of which lie on the very watershed beyond the upper lake. Indeed it may be said generally that moraines and morainic *débris* are exceedingly plentiful in North Harris.

In South Harris there are fewer mountain-glens, and moraines are not so abundant. The finest examples we saw were at the mouth of a valley near Traigh Losgcinntir, where the bed of the valley was packed with well-formed hummocks and cones of moraine matter. Nowhere else, as far as I know, do pronounced moraine mounds occur in South Harris. Loose moraine-like *débris* is sprinkled here and there over the surface of the ground in the neighbourhood of many of the hills; but this material proved in many cases to be merely decomposed or disintegrated till.

With regard to the composition and structure of these moraines little need be said. They consist of earth, earthy sand, triturated and comminuted grit, angular gravel and *débris*, and large angular unpolished blocks of gneiss. Sometimes these blocks are subangular and rudely smoothed; but this is quite exceptional. Occasionally patches of gravel and sand make their appearance in the moraines, and sometimes the morainic materials themselves show a kind of rude bedding, the position of the stones indicating the direction in which they were "shot." The mounds are generally of small size, and often pave the whole bottom of a mountain-valley, at the mouth of which they not infrequently spread out so as to cover a fan-shaped area. As already indicated, they are very often crowned with large angular erratics.

Again and again we see morainic matter resting upon till in such a way as to prove beyond question its more recent origin, as may be seen in the accompanying section (Fig. 10). On the other hand, simi-

Fig. 10.—*Till and Morainic débris, Fincastle Road.*



a. Till; *m.* Morainic *débris*, showing rude bedding.

lar *débris* often passes insensibly into till, so as to form part and parcel of the same deposit. Thus it is evident that the moraine matter does not belong exclusively to one and the same period. Some of it is as old as the till, while some, again, is certainly more recent. And the same may be said of the loose erratics and perched blocks.

7. *Origin of Erratics and Moraines.*—The origin of the deposits in question seems sufficiently obvious. When the great sheet of ice that overflowed Harris began to melt away, it is evident that a time would arrive when it would be no longer able to override the higher elevations of the island. These, therefore, would begin to rise, as it were, more and more prominently above the level of the *mer de glace.* The margins of the ice-flow would now be dotted with big blocks and *débris* showered upon it from slowly emerging crags and cliffs; while, at the same time, much moraine matter would doubtless be carried down to it by small local glaciers, streaming outwards from such glens as those that drain the Langa, the Cliseam, and the lofty mountain-tracts of North Harris. Then a time would at length arrive when these local glaciers would cease to coalesce with the great *mer de glace*, and when the latter itself would be unable to overflow even the lower parts of Harris. Under such circumstances, all the mountain-tracts that were capable of sustaining glaciers would have their small local glaciers, whose moraines would be deposited at higher and higher elevations as the climate improved, and the snow-fields melted away. Some of these small snow-fields, moreover, even although they gave rise to no true glaciers, might yet have succeeded in scattering erratics locally in large numbers, either suddenly by avalanches, or gradually and continuously by the downward movement of the snow and *névé.*

The morainic *débris* that passes into and forms part and parcel of the till belongs, I believe, to the time when the ice-sheet was decaying and receiving tributary glaciers from the mountain-glens of Harris. To this time also must belong many of the large erratics that are scattered over the mountain-slopes of the island. During this stage we may readily conceive that the direction of ice-flow in some valleys would be very different from what it had been when the land lay buried at its greatest depth. Each local glacier would now follow the course of its valley, which might or might not coincide in direction with the flow of the *mer de glace*. That such was the case we have evidence to show. I have already pointed out that the region between Loch Seaforth and West Loch Tarbert is glaciated from south-east to north-west. This is proved by the trend of striæ, by the *Stoss-seite* of *roches moutonnées*, and by the phenomena of the till. The glaciation of Beinn Chulish and the hills above the Tarbert points to the north-west; but in the valley occupied by Loch Lacasdail the striæ run down the valley towards East Loch Tarbert—that is, in almost exactly the opposite direction. As we follow the striæ and *roches moutonnées* down the valley, however, we find them gradually turning away to the west, until the lines of glaciation sweep round the hill above the Tarbert and assume the normal north-westerly course. This remarkable deflection proves that the local glacier of Loch Lacasdail coalesced with and was forced out of its south-east direction by the great *mer de glace*, which, although at this time considerably reduced in thickness, was yet able to stream through the Tarbert into the Atlantic. Whether, even when the ice-sheet was at its thickest, there may not have been in the bottoms of such deep glens an under-current setting down the valleys while the upper portion of the ice-flow streamed away in the general north-westerly direction, is a question which future investigations will probably answer in the affirmative.

Long after the *mer de glace* of the Minch had ceased to impinge upon Harris, the higher valleys continued to hold glaciers, and some of these were of considerable size, comparatively speaking. Terminal and lateral moraines, more or less well developed, occur in all the glens of North Harris visited by us; and the striæ in such glens were, as a rule, fresher than those on the hill-tops and in the more open parts of South Harris which have never supported local glaciers. I may refer specially to the striæ in the valley of Loch Lacasdail, which are wonderfully well preserved, contrasting strongly with the smoothed faces of rock on the higher slopes above the Tarbert, from which the striæ have in most cases entirely disappeared. The contrast between the general and local glaciation is perhaps seen to best advantage in the valleys that come down from the Cliseam and the Langa. In Gleann Abhuinn-eadar, for example, there are not only well-marked moraines, but the rocks in the glen itself give evidence of having been ground and rubbed by a local glacier flowing *south*, while the hill-tops overlooking the valley from west and east are all finely glaciated from south-east to north-west, the ice-worn surface extending up to a height of 1600 feet at least.

I have mentioned that moraines and morainic *débris* occur in greatest profusion in the more mountainous districts of Harris.

The same holds true of erratics. They are exceedingly numerous in North Harris; but in South Harris, although they are plentiful enough, they only in a few places occur in particular profusion. They are rather numerous, for example, in the neighbourhood of East Stoc-cleit, where they are dotted over *roches moutonnées*, till, and morainic *débris*. Many of the erratics in South Harris, however, have been derived from the till; and the same, of course, is true to a considerable extent in North Harris also. The till contains numerous boulders of precisely the same character as those lying loose at the surface. Often, indeed, it is merely a coarse aggregation of large and small angular and subangular blocks and *débris*. Again, over wide areas in South Harris, particularly in the bare rocky districts that slope towards the Minch, its only representatives are large blocks and smaller stones scattered loosely and sparsely over the surface, many of them quite angular and others more or less abraded and blunted. Such is the character of the "till" wherever the ground opposes a more or less abrupt declivity to the south-east; it consists of a mere sprinkling of erratics and small angular and blunted boulders, which here and there gather into heaps on the north-west or lee side of *roches moutonnées* and prominent crags. But the larger angular erratics and perched blocks occur decidedly in greatest abundance on mountain-slopes and in valleys which have contained local glaciers.

8. *Freshwater Lakes and Sea-lochs.*—The freshwater lakes of Harris, although numerous, do not form so striking a feature in the scenery as those of Lewis and other parts of the Long Island. Excellent bird's-eye views of the Harris lakes are obtained from the tops of the Cliseam, the Langa, Clisebhal, and other hills in North Harris, and from Cluinisbhal and Roinebhal in South Harris. Like a large number of those in Lewis, many of the Harris lakes range themselves along the line of strike, those that lie across that line being chiefly confined to mountain-glens. The larger number of the lakes and lakelets we visited appeared to rest either in complete rock-basins or in hollows formed partly in rock and partly in till or other glacial *débris*. Many, however, are mere shallow pans, and have been encroached upon by peat. Some of the more interesting of the N.W. and S.E. lakes are scattered over the rocky tract between Roinebbal and Cluinisbhal, where they form a very picturesque contrast to the weird, grey, glaciated, and weather-worn *roches moutonnées* amongst which they lie. All these clearly belong to the period of general glaciation, and have nothing whatever to do with local glaciers. The strike of the gneiss in Harris not wheeling about as it does in Lewis, there are no "strike-lakes" corresponding in direction to the N.E. and S.W. lakes of the region lying to the west and south-west of Stornoway.

The linear lakes whose trend does not coincide with the strike of the gneiss are, as I have said, confined to mountain-valleys, and owe their origin to the action of local glaciers, the terminal moraines of which occur in the immediate vicinity. Hence they follow the trend of the valleys, which may sometimes be at right angles to the direction of the general glaciation. Good examples of such local glacier-lakes occur in Gleann Abhuinn-eadar and Bealach na Ciste; and Loch Lacasdail itself is another excellent example. In the case of this lake, however, it is highly probable that the work of excavation was partly accomplished during the time of general glaciation. The same to some extent holds true, I am inclined to believe, of some of the lake-basins in the mountain-tracts of Lewis,—of Loch Suainabhal, for example. That rock-basin, however, has evidently been occupied by a large local glacier in late glacial times, and doubtless experienced considerable erosion then. The moraines of the glacier in question are seen crossing the valley below Loch Stacsabhat. Of rock-basins which are entirely due to the action of local glaciers the mountain-valleys of Lewis afford a number of good examples; but the lakes are usually small. Among these may be mentioned Loch Raouasgail, between Mealasbhal and Taithabhal, which is half a mile in length and about a sixth of a mile in breadth. Loch Dhibadail, about the same length but only half as broad, is another good example; it lies at the base of the steep slope of Tamanaisbhal.

Of the sea-lochs that intersect Lewis and Harris not much need be said. In none of them are found the great depths which are so characteristic of the fiords of Western Sutherland and Ross. And this might well have been expected. There are deep rock-basins in Loch Torridon, Loch Ewe, and Loch Broom, because all those fiord-valleys were once filled by gigantic local glaciers, fed from some of the loftiest and most extensive snowfields in glacial Scotland. But in late glacial times only inconsiderable glaciers occupied the mountain-valleys of Harris and Lewis, and it is extremely doubtful whether many of these lingered for a prolonged time in the sea-lochs after they had ceased to be confluent with the *mer de glace* of the Minch*. There is a depression in Loch Seaforth that reaches a depth of 138 feet, and another occurs in Loch Shell which is 60 feet deeper than the outlet of the Loch. The bottoms of Loch Claidh (Clay) and Loch Bhrollum seem to be similarly excavated; but the soundings given upon the Admiralty charts are not sufficiently numerous to make this quite certain. It is interesting and suggestive to find that these depressions occur in the very places that must have been occupied by considerable local glaciers, which, when the pressure and obstruction of the *mer de glace* of the Minch were beginning to decrease, would commence creeping out from the mountains down all the main lines of drainage. In some cases these local glaciers would flow at right angles to the course followed by the general ice-sheet in the same localities, as was certainly the case with those glaciers that descended from the Forest of Harris towards West Loch Tarbert. In other instances the course of the local glaciers would even be directly contrary to that of the *mer de glace*, as we have seen was the case with the glacier of Loch

* It may be as well to state here that I take the liberty throughout this paper of applying the term "the Minch" to all the sea that lies between the Outer and Inner Hebrides.

Lacasdail, and as may have been the case also with the local ice in the lower reaches of the hollow now occupied by Loch Seaforth. It is quite possible, however, that the depression in the bottom of that sea-loch may owe its origin in some degree to the action of the great *mer de glace* itself, which streamed through this hollow into the low grounds of Lewis, and which must have been subjected to great compression and strangulation in the very place where the depression or excavation now exists.

The sea-lochs that enter the island from the west contain no rock-basins; and this is evidently due to the absence of any considerable local glaciation. The local glaciers in that part of the island seem to have occupied themselves chiefly in the excavation of those small rock-basins in mountain-valleys that now hold fresh-water lakes. From the configuration of the ground, indeed, it is obvious that no large local glacier could ever have entered Loch Roag. Nor could Loch Resort in late glacial times ever have received the same quantity of local ice as seems to have streamed into Loch Seaforth.

IV. Islands in the Sound of Harris.

The Sound of Harris is very shallow, and studded with countless rocks and sandy shoals. Indeed there is only one narrow track for vessels through this dangerous channel, and in some places the track has not more than 5 or 6 fathoms of water. We did not land upon any of the little islands, but boated round them and about them. They all afford strong evidence of having been abraded by glacial action. Papeidh has quite the rounded glaciated outline, and so have the hills in Bearnareidh. The islands of Einseidh and Ceilegreidh are flat; but they also show *roches moutonnées*, and well-rounded rocks are likewise conspicuous in the Grotheidh group of islets. In Giliseidh and Lingeidh the gneiss dips north-east at an angle varying from 50° to 65°, and on the former islet are some perched blocks. The same dip is found in the Harmatreidh group, and there seems to be some till on the island of Harmatreidh itself. The glaciation on all these islands has the same trend as that of Harris; it coincides in direction with the Sound.

V. North Uist.

1. *Physical Features.*—North Uist (14 miles from north to south, and 15 to 17 from west to east) exhibits much the same kind of scenery as portions of Lewis and Harris. A ridge of very rugged hills runs along the east coast, and attains a height in Beinn Ebhal of 1133 feet. The central portion of the island might aptly be described as a wide peat-bog, interspersed with innumerable irregular peaty lakes, which are apparently quite shallow. From this flat central area the land rises towards the west, forming a rolling hilly tract in which there are but few lakes. Along the north-west, west, and south-west coasts the ground is low and level, and shelves gently into the sea, so much so that at low tide very extensive tracts of sand are exposed, and the adjoining island of Benbecula may then

be reached on foot. The east coast is bold and rocky, and is penetrated by arms of the sea, one of which (Locheport) all but succeeds in bisecting the island. The coast-lines of these sea-lochs are unusually intricate, there being, it is said, several hundred miles of coast measured by the Admiralty surveyors in Loch Maddy alone. The most fertile portion of the island is the somewhat narrow belt that extends along the west coast, where the fertility is largely due to the presence of shell sand. The major part of the island, however, is desolate in the extreme, the rocky ridge of Beinn Ebhal resembling in character the grey and weathered mountains of Harris, and the lower grounds vividly recalling the brown sombre moorlands of Lewis. There are no streams worthy of the name.

2. *Geological Structure.*—Gneiss and its varieties form as usual the solid substratum of North Uist, with occasional intrusions of basalt. The general strike of the beds continues much the same throughout the greater part of the island, the dip being towards north-east in the districts north of Locheport. In the south and east there is a good deal of contortion and confusion, and the dip is sometimes north-west, while now and again the beds approach horizontality. In Beinn Ebhal there is a peculiar schist, which in places approaches the character of clay-slate. Macculloch describes a number of peculiar metamorphic rocks as occurring in parts of the east-coast mountain-range, which we did not visit. These sometimes assumed the character of a "lead-coloured compact felspar," a "siliceous schist," a "felspar-porphyry," and now and again passed into granite, hornblende-schist, and gneiss. We did not see any of these nondescript rocks *in situ*; but many boulders of them occur in the till of the low grounds, and are scattered over the district to the north of Cairnish.

3. *Glaciation.*—The most intensely glaciated part of North Uist is beyond question the rocky ridge that extends along the east coast. The hills in the west are also well rounded; but in the central low grounds the rock is for the most part obscured below till and peat, although innumerable ice-worn hummocks and tors of gneiss peer through the superficial covering.

Between Leacali and Weaver Point the hills that face the sea are ice-worn all over and in the usual direction. The bedding of the gneiss hereabouts is very obscure. Between Loch Maddy and Locheport the hills rise to upwards of 900 feet, and are also highly glaciated from base to summit. They present a sloping surface to the Minch, and a steep face to the interior, and are as destitute of soil and verdure as the bleakest mountains of Harris. Beinn Ebhal and the hills in its vicinity are ice-worn in the same manner, the grey rounded rocks having evidently been smoothed off from the direction of the Minch.

In the Crogaire range, which attains a height of about 600 feet, and rises on the west coast near Bhalacui, we found the north-west direction holding equally true, the striæ on different parts of the hills pointing W. 12° N., W. 15° N., W. 20° N., W. 35° N., and W. 40° N. Peighinn-mhor (621 feet) in the north is glaciated in the same direction. South-east of the Crogaire hills, in the moors, striæ were met with here and there, agreeing in direction with those just given, the average being W. 35° N. Mr. Campbell * gives the bearing of striæ "at Loch Maddy, on the east coast, and the northern corner, next to the Sound of Harris," as "about 45° W." In the neighbourhood of Loch Maddy I found striæ pointing nearly the same, namely W. 40° N. Along the road leading from Loch Maddy to Clachan good glaciated faces are seen again and again, peering from under the till or freshly exposed. But on rocks that have been long bared of their covering the markings are very faint; for the gneiss of North Uist seems to be upon the whole a less durable rock than much of that in Harris. Unfortunately the old map of North Uist used by me contains but few names, and its topography leaves much room for improvement; but I will indicate as near as I can the localities where striæ were noted. About one mile south of Loch Maddy Inn, on the side of the road, are striæ bearing W. 5° N. Between that spot and the shores of Loch Scadabhagh a number of glaciated faces occur, upon which the direction varies from W. 5° N. to W. 15° N. Immediately beyond the loch the striæ again point W. 5° N. After this the road leads through a district where few rock-faces are seen. Between the Barp and Clachan, however, we get striæ again bearing W. 5° N. Coming south from Clachan about 2 miles or so I got one bearing of W. 10° N., but more were observed between that and Cairnish. In the neighbourhood of the latter place several bearings were taken, the directions varying from W. 7° N. to W. 10° N.

Between North Uist and Benbecula are a number of islands, of which the two largest are Grimiseidh and Roneidh. The former we saw from both ends, but did not land upon. It has the usual ice-worn outline. So has Roneidh, which we coasted sufficiently near to obtain the dip of the gneiss (which is at a considerable angle to the south-east), and to assure ourselves that its bare rugged hills have been glaciated from south-east to north-west.

4. *Till or Boulder-clay.*—The till of North Uist presents much the same character as that of Harris and Lewis. It is usually of a drab or dirty grey colour, and may be described as a hard, gritty, and sandy clay, containing much comminuted gneissic material, with the usual blunted and subangular and angular stones, somewhat irregularly aggregated. In many places, however, it can hardly be called a clay, but is rather a sandy and clayey grit. Irregular nests, patches, and lenticular beds of sand, gravel, and earthy *débris* are enclosed here and there in the till. Striated stones are sometimes scarce, while in other places they are unusually plentiful. Most of the stones, however, are more or less distinctly abraded; but the proportion of angular fragments is almost always large. The stones are of all sizes, from mere grit up to blocks measuring several feet or yards across. The till reaches and occasionally exceeds 10 feet in thickness, but is usually thinner.

Many appearances connected with the till point to an ice-flow

* Quart. Journ. Geol. Soc. vol. xxix. p. 547.

from the south-east. We see this shown, in the first place, by the distribution of the deposit. It does not occur along the rocky east coast, but comes on in force behind the ridge of Beinn Ebhal and Beinn Li; and it tends to gather most continuously over low-lying and gently inclined ground, where there were no obstacles to the overflow of the ice from the Minch. Excellent illustrations of these phenomena occur in the neighbourhood of Loch Maddy. Thus immediately behind the ridge of high ground that forms the eastern boundary of the loch thick till is seen sloping down to the sea. Till likewise occurs in similar sheltered places on the northern shores of Loch Maddy, as along the eastern margin of Loch Partan Channel. Again it may be seen on some of the flat islets in the loch, such as Flodeidh and Hamarseidh; and here and there also along the shores of Loch Theoravagh good sections are obtained. It does not occur upon the rough ground facing the Minch, simply because over that area excessive grinding action necessarily prevented its accumulation; it gathers thick in the rear of the east-coast ridge because there it experienced some shelter, and it spreads out thinly over the wide low grounds of the interior because in that region the ice, meeting with no obstructions, probably flowed with a smooth, equal, and somewhat slower motion.

The direction taken by the ice is yet further shown by the rude arrangement of stones and boulders in those deposits of till that occupy the lee-side of prominent rocks. This may be seen in many of the openings made on the sides of the roads throughout the island; but as the phenomena are precisely the same as those mentioned in connexion with the till of Harris, they need not be further described.

Lastly, the trend of the old *mer de glace* is marked out by the boulders which have been pushed from Beinn Ebhal and Beinn Li westwards into the interior. In the till of the central low grounds occur many boulders of various peculiar rocks which are found *in situ* in the east-coast ridge, but not in the interior. Conspicuous among these are a dark blackish-green hornblende-rock and hornblende-schist, and various slaty and schistose rocks. Another well-marked stone which is of frequent occurrence in the till is a dark greenish felspathic and hornblendic rock, thickly set on weathered faces with points of a hard pink-coloured mineral which I could not at the time determine, and the specimen I brought away has unfortunately been lost. Macculloch refers to this rock as being exposed upon the east coast, where, according to him, it is "thickly strewed with prominent points, the crystals of a harder matter which has resisted corrosion," from which, perhaps, it may be inferred that he was equally unable to determine what the hard pinkish mineral was. Boulders of a granatiferous gneiss, which have probably come from the same quarter, are associated in the till with the varieties just mentioned.

5. *Erratics.*—Comparatively few angular erratics are scattered over North Uist. Nearly all those we saw were either enclosed in the till, or had probably at one time been so. They were for the

most part blunted, and showed traces of glacial abrasion, but now and again they were quite angular. But even amongst the hills of the east-coast range large angular erratics appeared to be by no means so common as in North Harris, and I saw no trace of terminal moraines. In short, evidence of local glaciation appears to be wanting, and if any local glacier ever did exist it must have been of insignificant dimensions.

6. *Freshwater Lakes and Sea-lochs.*—The low-lying parts of North Uist are thickly interspersed with shallow lakes that wind about in the most intricate manner, although they appear upon the whole to have a tendency to lengthen out in the direction of glaciation. Most of them have peaty margins, and seem to rest partly in till and partly in gneiss. The sea-lochs are of the same general character. They are very shallow, the soundings showing that an elevation of only 50 or 60 feet would be enough to dry up Loch Maddy and Locheport. Their coasts are low and flat, and save the saltness of their water they have hardly any thing else in common with the fine sea-lochs of the mainland, or even with those of Lewis and Harris. As no local glaciers existed in North Uist, mountain-valley lakes do not occur.

VI. Benbecula.

The physical aspect of Benbecula is much the same as that of the low-lying flats of North Uist and Lewis, but the proportion of water to land is greater. In fact it is hard to say whether land or water occupies the larger area in Benbecula. The island measures $6\frac{1}{2}$ miles or so from west to east, and about a mile or so less in the opposite direction. It has only one hill; and if we except the "Machair," as the "good land" along the west coast is called, all the rest of the island consists of low-lying moor, bog, and lake, with long shallow inlets of the sea straggling in, chiefly from the east coast.

Till of the usual character is widely diffused, with here and there worn and glaciated rocks peering through. Striæ appear to be seldom preserved. I noticed only one example, and the markings were rather faint; their direction was W. 12° N. I saw no erratics that might not belong to the till, and it need hardly be added that there are no moraines. The dip of the gneiss, I should mention, is towards north-west at various angles, from 25° up to nearly vertical. In Fuitheidh, however, the strike is almost at right angles to that of Benbecula, and the dip is south-west. The hills on the latter island are highly glaciated.

VII. South Uist.

1. *Physical Features.*—South Uist is some 20 miles in length, and has an average breadth of 5 or 6 miles. It is separated from Benbecula by a narrow channel, which at low water may be forded. Its west coast is somewhat regular; but the opposite coast-line is extremely intricate, especially north of Huisnis. South of that point there are only two large inlets of the sea, Lochaoineart and Loch Baghasdail (Loch Boisdale); but they ramify far into the

interior, reaching nearly to the west coast. Two thirds of the island are mountainous, the remaining portion forming a narrow belt of low ground that faces the Atlantic. With the exception of this low-lying strip, which extends from north to south along the whole length of the island, and does not average more than a mile in breadth, and the moory district in the north, which is cut up by Lochbi, Lochsgiport, and Lochcarnan, all the rest of the island is mountainous. The dominant points are ranged, as in North Uist, along the east coast, and form a broken and interrupted ridge which rises to elevations of 2000 feet and more. These mountains have precisely the same character as those of the islands already described; they present for the most part an undulating and rounded outline, save in the cases of Hecla and Beinn-mhor, the tops of which are somewhat sharp and peaked. The low grounds also find their exact counterpart in the moory flats of Benbecula and North Uist. Adjoining the sandy shore are the delightful "machairs," with their wealth of bright colour; while inland from the "machairs" stretch the brown sombre peat and moorland, intersected in all directions, as usual, with shallow freshwater lakes. The only streams of any importance are those that flow from the knot of high ground in the middle of the island.

2. *Geological Structure.*—South Uist shows nothing remarkable in its petrology, so far as we saw. The prevailing rock is gneiss, but green slate and schist occur in the island of Staoleidh. Dykes of basalt are also occasionally met with, some fine examples being visible in the cliffs a little to the north of Staoleidh. In the north of the island near Lochbi the strike of the gneiss is nearly north and south, the beds dipping west at a high angle. Near Dreimsdal the strike runs a little east of north and west of south, the dip being to the north of west. From Beinn-mhor south to Eirisgeidh Sound the average strike is about W. 15° or 20° N. and E. 15° or 20° S., sometimes more and sometimes less, the beds being generally vertical.

3. *Glaciation.*—South Uist affords every evidence of having been subjected to intense abrasion, and next to Harris is perhaps the island of the Outer Hebrides which has most interest for a glacialist. *Roches moutonnées*, glacial striæ, till, erratics, and perched blocks, evidence of the general or primary and local or secondary glaciations and of the maximum thickness attained by the old *mer de glace*, may all be studied in South Uist.

Striated rock-faces are of frequent occurrence. Without leaving the road for any distance I took the bearings of about forty examples between the South Ford and Pollachara, and in the neighbourhood of Loch Baghasdail or Boisdale and Beinn-mhor I got also a considerable number. Some are as fresh as if they had been recently graven, others are weathered and faint, and some are so faded that a good light is needed to bring them out.

Close to the South Ford are striæ pointing W. 15° N.; and further south than this, about a mile and a half from the Ford, at a place called Iocar, there is a finely glaciated face, which Mr.

Campbell has referred to*. The bearing I got here was W. 10°–15° N. Mr. Campbell, however, gives N. 65° W. magnetic, and mentions that a stick laid in one of the grooves pointed directly to the Coolin Hills in Skye. But these mountains bear E. 18° S. from this particular place, so that the direction (N. 65° W. magnetic) he gives for the striæ has hardly enough northing. In Shiffrey Moor, near Lochbi, the striæ bear W. 15° N. South of Lochbi, however, they begin to swing round to south of west, several bearings between the loch and Crogaire giving W. 10° S. to W. 15° S. Between Crogaire and Dreimsdal the striæ point W. 8° S., W. 10° S., and W. 15° S.; and between this latter place and the river Torra the directions are W. 10° S., W. 15° S., and W. 20° S. Passing over the low boggy ground through which the Gheatra flows, we reach a finely striated face, a short distance north of Loch Hollai, which gives a bearing of N. 45° W. For two miles south of this the striæ continue to point nearly due north-west, but gradually assume more westing. Thus, one mile south of Loch Hollai they are W. 35° N., on the side of Beinn Corraivi W. 20° N., immediately south of that W. 10° N., and then due W. Between Airimhuilinn and Aisgernis are a number of striated rocks, on which the direction varies from W. 2° or 3° N. to W. 5°–8° N. Near Loch Hallan the bearing is W. 5° N., at Loch-nam-faoileann W. 3° N., near Loch Dun-na-cille W., between the School and Pollachara W. 15° N. and W. 35° N. A very fine striated face (E. and W.) is exposed in a pit on the side of the road at the foot of Cairisbhal. The direction of ice-flow is very plainly seen here; it is clearly from the east.

Mr. Campbell mentions other two localities, besides the one referred to above, where he observed striæ; but, owing to the paucity of names on the Admiralty chart, I am not quite sure of the places indicated by him. But as I walked the whole length of the island—half of the way twice over—and was on the constant outlook for striæ, it is hardly likely that I missed the striated rocks mentioned by Mr. Campbell. He gives N. 40° W. magnetic as the bearing of striæ at Birsdale, in a quarry by the roadside. The other direction he gives is "about halfway up the island, about 100 feet above the sea-level, in the flat country on the west side of the hills, near a large perched block." The bearing given is N. 52° W. magnetic, and "the grooves point at a gap in the chain of hills." This, I have no doubt, is on the roadside near the foot of Beinn Corraivi, where I obtained the same bearing.

The hills that face Eirisgeidh Sound are very highly glaciated, and the direction of ice-flow is quite apparent; it is W. 20°–30° N. The range of hills between Loch Boisdale and Lochaoineart are also severely glaciated, their bare bald summits being distinctly smoothed. We tried to climb Staolabhal (1227 ft.), but were prevented by stormy weather; but, as seen from below, the mountain has all the appearance of having been smothered in ice, and the hills between it and Loch Boisdale have certainly been so, their *roches moutonnées* being rounded off from the south-east. We boated down Loch

* *Op. et loc. cit.*

Boisdale, and round the coast to Lochaoineart, and were much impressed with the appearance of severe glaciation on the seaward faces of the Loch-Boisdale hills. Opposite Staoleidh we landed, and got striæ pointing inland about W. 10°–15° N. We landed again on the north shore of Lochaoineart, and crossed over the shoulder of Beinn-mhor, the day unfortunately proving unfavourable for the ascent to the summit, which was shrouded in thick mist. The general or primary glaciation in this neighbourhood is very striking. A number of bearings gave as nearly as possible the same direction, namely N. 35° W., some of the striæ being very distinct and others rather faded. The *roches moutonnées* are wonderfully preserved, and show the direction of glaciation very clearly. But one of the most interesting features noticed here was the evidence of a local or secondary glaciation, which will be described further on. We traced glacial striæ up to a height of 1150 feet at least, the direction being, as before mentioned, N. 35° W. These striæ did not slope down the hill, but were horizontal. Although thick mist prevented our getting to the top of Beinn-mhor, we yet had an excellent view of the whole hill when we descended to the low ground; for the mists suddenly cleared off, and left every thing bathed in sunshine. Estimating from the highest point we reached, which we could distinguish quite well from below, the ice-worn *moutonnée* surface appeared to extend upwards to within 300 or 400 feet of the summit, which is 2033 feet above the sea. The upper non-glaciated part is a sharp, somewhat serrated or ragged ridge, from which long slopes of *débris* shoot down to the glaciated shoulders of the hill, which they encroach upon and partially obscure. Hecla (1988 feet) is the only other hill in South Uist whose top rises above the limits of the primary or general glaciation. Nothing can be more distinct than the line of demarcation between its sharp, jagged, peaked summit and its rounded, softly outlined shoulders, with their *moutonnée* surface. We saw this mountain under every advantage from the land, and again from the sea at no great distance from the shore, and it always presented the same striking contrast. Unfortunately our time did not permit us to explore it and the hilly region to the north-east.

A glance at the accompanying map (Pl. XXXIII.), on which the principal bearings are inserted, will show a curious change in the direction of the striæ about the middle of the island. This change is unquestionably due to the presence of Hecla, Beinn-mhor, and the mountain-masses in their vicinity. The *mer de glace* flowed against the mountains from a little south of east, and, streaming round the obstruction, gave rise to two sets of striæ in its rear, which a reference to the map will show differ in direction from the average or normal trend of the ice-flow in South Uist. The phenomena are precisely the same as may be witnessed in the bed of any stream containing large boulders. The water, forced aside to right and left by an obstacle in its path, gives rise to two currents, which flow in again from either hand to meet each other at some distance behind the boulder or rock that forms the obstruction. Doubtless could we examine the rocks at the sea-bottom some little distance out from the shore, we should find as we approached Beinn-mhor that the striæ were deflected towards the south-west, while opposite Hecla the deflection would be towards the north-east. It will be remembered that a deflection like this occurs in North Harris in the neighbourhood of the Cliseam.

4. *Till or Boulder-clay.*—The till of South Uist is gritty and earthy, with but little admixture of clay. Here and there it becomes very sandy, and near the hills it is often extremely coarse, being crammed with rude angular and subangular *débris* and boulders, some of which attain a great size. Here and there the stones are fairly well striated; but in other places one has to look narrowly for even one. Blunted shapes, however, are as numerous as usual. At Loch Boisdale there is a good example of a "striated pavement" in the till. Close to the village is a pit dug in a gritty greyish-yellow and blue clay, with scattered boulders of gneiss, most of which are more or less well glaciated. A number of large boulders sunk in the clay, and the surfaces of which are approximately on the same level, are all striated across in one and the same direction, W. 25° N.

The distribution of the till is much the same as in North Uist; it does not occur, save only in little patches, amongst the hills on the east coast, but spreads over considerable areas on the low grounds to the west. It has the same tendency also to gather on the lee-side of *roches moutonnées* and jutting crags; and one may also trace, again and again, in such sheltered places that rude dip of the stones and boulders away from the protecting rock to which reference has so frequently been made in my description of the till in Harris and the other islands. Crumpled and contorted beds of sand and gravel likewise occur in the till, pointing to the manner in which that deposit was crushed and rolled forward under the ice. I also met in the till with some small boulders of a dark earthy amygdaloidal melaphyre, closely resembling some of the igneous rocks in Skye, but unlike any basalt-rock I ever saw in the Outer Hebrides. At Crogaire I picked out of the drift a small boulder of conglomerate, which might have come from some Cambrian deposit. But these were the only boulders which I was pretty sure did not belong to South Uist. At the same time I think it is not improbable that many of the erratics of syenite, quartz-porphyry, and other crystalline rocks which appear in these islands may really be visitors from some of the Inner Hebrides, or even perhaps from the mainland. At the foot of the Boisdale Hills opposite Staoleidh I saw boulders of green slate which may have come from that island, where such green slate and schist are well known to occur.

5. *Erratics, Moraines, and Local Glaciation.*—Very few erratics are found in the low grounds of South Uist, and those that occur probably belong to the till, for many show traces of glacial abrasion. Along the foot of the hills, however, angular erratics are here and there plentiful, one very fine example of a perched block occurring immediately above the road a mile or more north of Airimhuilinn. Here and there also one comes upon sprinklings of morainic *débris*

close to the base of the hills. This *débris* and the large perched blocks no doubt both belong to the time when the *mer de glace* was waning, and the hills of South Uist were becoming more and more uncovered. I saw no trace of any small valley-glacier having descended the hills to the west, all the erratics and morainic matter of that region having been laid down, as I believe, when the ice-sheet was melting away. But in the neighbourhood of Beinn-mhor we have evidence of a considerable flow of ice towards the south-east into Lochaoineart. The evidence consists of striations and perched blocks. Due south from the top of Beinn-mhor the lower slopes of the hills facing Lochaoineart are glaciated in the direction of the loch, as indicated upon the map, and a number of large boulders are perched upon the slopes which have evidently been carried down from Beinn-mhor. It is clear, however, from the height reached by these secondary striæ and the perched blocks, that it was no ordinary local glacier that passed down the lower reaches of Lochaoineart. It seemed to me that we had here quite the counterpart of what we found in the valley of Loch Lacasdail and in the neighbourhood of the Langa and the Cliseam, a change, namely, in the flow of the ice which was induced during the decrease of the *mer de glace* of the Minch. At a greater elevation the hills are distinctly glaciated in the opposite direction, and the well-rounded shoulders of Beinn-mhor itself attest that during the climax of the glacial period the whole region was overflowed from the Minch up to a height of not less than 1600 feet.

I saw no moraine mounds in the valleys coming down from Beinn-mhor to Lochaoineart. The nature of the ground, indeed, is not such as would favour the formation of local glaciers of any importance. If such ever hung on the southern slope of the mountain they must have been of insignificant size; for, as I have said, they have left no moraines behind them. I have little doubt, however, that moraines exist to the north in the valleys that come down to the Minch between Beinn-mhor and Hecla, a district which we did not traverse. All that can be inferred from the evidence which came before us is that during the greatest extent of the ice-sheet the flow of the ice was persistently across the whole island from the Minch to the Atlantic, and that when the level of the *mer de glace* began to sink, and the hills to be uncovered, local glaciers of considerable size (or small ice-sheets, as they might be termed) flowed down the slopes to coalesce with the waning ice-sheet. Thus a newer set of striæ was engraved upon the rock, the trend of which is sometimes nearly at right angles, and at other times runs in quite the opposite direction to the primary glaciation, according as the slope of the ground guided the local ice.

6. *Freshwater Lakes and Sea-lochs.*—The freshwater lakes of South Uist are, as far as we saw, restricted to the low grounds, and are of the usual irregular straggling character. Like those of North Uist and Benbecula, they appear to rest partly in rock and partly in till, and to have a tendency to lengthen out in the line of glaciation. No mountain-valley lakes seem to exist, unless it be in the hilly

tract between Beinn-mohr and Hecla, where a lake is represented on the Admiralty chart as lying in the valley that comes down to the bay called Bagh a Mhoile-deas. The sea-lochs are Lochcarnan, Lochsgiport, Lochaoineart, and Loch Boisdale. None of these is deep, the former two being studded with small rocky islets, and having for the most part flat monotonous shores. The latter two are bounded in their lower reaches by bold rocky hills; but they extend beyond the mountain-districts, Lochaoineart especially stretching far into the peaty low grounds of the west. Their coast-lines are quite as intricate as those of the freshwater lakes, and no deep depressions or excavations, like that in Loch Seaforth (Harris), are shown upon the Admiralty charts.

VIII. Islands in the Sound of Barra.

The Sound of Barra is very shallow, being studded with rocks and broad shoals of sand. We did not land upon any of the islets, but as we boated past them could see that each was more or less well glaciated. Eirisgeidh, the largest of the number, shows bare, highly *moutonnee* rock in the north and south. Lingeidh, Fuideidh, and Oroseidh are mere *roches moutonnées.* In Fuideidh the gneiss dips to the north-east. Gidheidh, Heiliseidh, and the adjoining islets all show a bare *moutonnée* surface. Some of the islands, such as Eirisgeidh and Fuideidh, have much yellow sand blown in upon them, chiefly along their western shores.

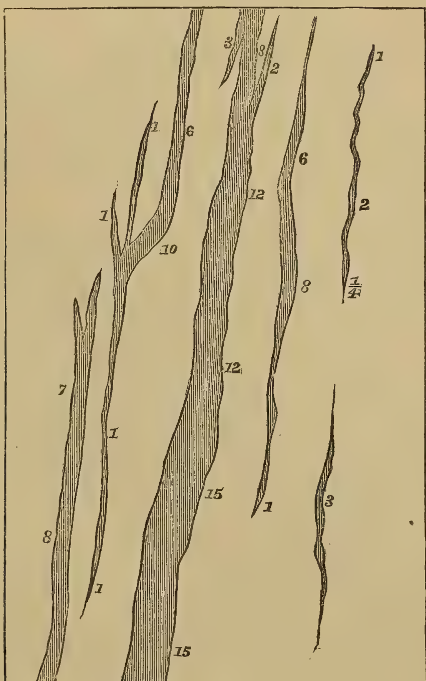
IX. Barra.

1. *Physical Features.*—Barra (8 miles long by 3 broad) is one of the most pleasing of these outer islands. Although almost wholly mountainous, it appears comparatively well clothed with verdure when we contrast it with the hilly districts of North and South Uist. Yet the higher parts of the hills are almost as bare as those of the latter islands. The dominant point is 1295 feet above the sea, near the south end of Barra. The hills in the northern portion do not attain a height of 700 feet. There are numerous small streams; but their fall is so rapid that they form no alluvial flats along their course. The only low grounds occur here and there along the west coast, where, as usual, there are considerable accumulations of shelly sand. Otherwise the coast-line is bold and rocky.

2. *Geological Structure.*—Barra, like the other islands, is composed almost exclusively of gneiss, veined with granite in places. In the northern part of the island the bedding is much confused, the rocks dipping in many directions, and now and again lying approximately horizontal. In the south half of the island this confusion disappears, and the strike runs persistently about N. 25° W. Basalt-dykes are specially numerous, the larger ones running north-west and south-east. But the smaller ones ramify in all directions, penetrating the gneiss in long sinuous veins that branch again and again, and split up sometimes into mere threads. The basalt of these remarkable veins is a hard, fine-grained, sometimes compact

black or very dark blue rock, and in some places, especially in the thicker parts of the veins, it is finely vesicular at its junction with the gneiss. In the broader dykes the rock is often vesicular in the centre, a common appearance in the basalt-dykes of the Lowlands. The accompanying sketch (Fig. 11) is a ground-plan of a surface of gneiss, showing some characteristic forms assumed by the veins.

Fig. 11.—*Ground-plan of basalt-veins intersecting gneiss, near North Bay, Island of Barra.* (Thickness of veins shown in inches.)



3. *Glaciation.*—Like all the other islands described, Barra is abundantly glaciated, the average direction of the striæ being about W. 35° N. The hills have the usual abraded and rounded aspect, and are distinctly smoothed off from south-east. But striæ are not so well preserved as a rule as in South Uist. The flanks of Beinn Eribhal in the north, which are highly glaciated, only showed striæ in two or three places, which pointed W. 30° N. The rock here is a coarse-grained hornblendic gneiss, penetrated by granite-veins and weathering rapidly. Along the east side of the island striæ were noted in a number of places, all of them agreeing in direction, W. 30° N. to W. 35° N. At Castle Bay striæ occur close to the sea-shore, the bearing given by Mr. Campbell being N.N.W. true. But there are a good many other striated faces in the immediate

neighbourhood, the bearings of which vary from N.N.W. to W. 35° N. On the slopes of Beinn Heabhal, at about 900 feet above the sea, I found them pointing N. 35° W., and the same direction occurs on the ridge between Castle Bay and Tangasdal on the west coast. But higher up the hill to the right the direction is W. 35° N., and this is also the trend on the high hill (Tangbhal) that forms the south-west corner of Barra.

That the contour of the island must have been, in preglacial times, much more rugged and broken is well seen in the bevelled or smoothed-off appearance which the edges of certain cliffs on the southern slopes of Beinn Heabhal present. This appearance is very conspicuous from the north shore of Castle Bay.

The hills overlooking Borgh from the north are finely glaciated, the striæ bearing W. 35° N. to W. 40° N. A mile or so further to the north they point W. 5° N. The road leading across the island by Loch an Dun is overlooked by highly glaciated hills. A number of striæ met with in the hollow through which this road runs pointed W. 10° N. to W. 12° N.

Barra is traversed by several hollows from shore to shore in a direction that coincides with the trend of glaciation. This coincidence, however, I am inclined to think is merely accidental, although the hollows have, no doubt, experienced considerable glacial erosion. They probably occupy lines of weakness, and owe their development, in the first place, to ordinary atmospheric and aqueous erosion in preglacial times. In some cases they are excavated along the line of basalt-dykes, which, as a rule, in these islands weather much more rapidly than the gneiss which they intersect. In other cases they may lie in faults, while some certainly coincide with the strike of the gneiss. In addition to these hollows, in which streams and brooks are now constantly or intermittently flowing, there is a minor set of dry hollows that cross the line of strike nearly at right angles, namely from south-west to north-east. I noticed these only in the southern part of the island, and they are best seen when the ground is viewed from a little distance. I could not satisfy myself as to their origin. They can hardly be faults, but may possibly represent great joints. When we reflect upon the enormous time these rocks of the Outer Hebrides have been exposed to subaerial denudation (they probably represent the oldest land-surface in Britain), we cannot be surprised to find structural peculiarities so strongly brought out. The valleys and hollows that coincide with the trend of the glaciation are, as a rule, broad and deep, and generally smooth and continuous, having evidently been greatly modified by the grind of the ice. Those hollows, on the other hand, that do not follow the trend of the ice are usually, but not always, narrow, shallow, irregular, and interrupted.

4. *Till or Boulder-clay.*—The till is, as usual, of a dark or dull bluish grey or greyish blue, sometimes paler, and now and again it shows a brownish tint. It is seldom a true clay, but, as a rule, merely a gritty earth, well packed and rammed so as to become tough and unyielding. Finely divided argillaceous matter is usually

diffused through it. The stones vary in size from mere grit up to large boulders several yards in diameter. The boulders are generally irregularly aggregated, in some places gathering together so as to form a coarse breccia, with a scanty gritty matrix; in other places occurring only sporadically in a matrix through which smaller stones are more equally distributed. Here and there one may detect rude attempts at bedding, the stones being arranged in sloping lines behind projecting rocks, whose glaciated faces look towards the south-east. Occasionally, too, one comes upon traces of lenticular patches of earthy gravel and sand. Many of the stones are well smoothed and they often show striæ, some of the larger blocks being beautifully polished and striated on one or more sides. In general the stones are blunted and subangular, but sharply angular fragments are always present in larger or smaller numbers. The till occurs in mere patches, and never occupies any wide area. It lies in nooks sheltered from the east and south-east, and also sprinkles the surface of the wide open valley to the east of Cuithir (Cuir). As a rule the deposit is very thin, the greatest depth I saw being only 8 feet.

5. *Erratics.*—Loose stones and large blocks are scattered over the island. Not a few of these are glacially abraded, but many are quite angular. The ice-worn boulders are in some cases merely the wreck of the till, the finer materials of which have been denuded away. In other cases they probably represent all the "till" that ever existed. Some of the angular non-glaciated erratics attain a very large size; an immense boulder that forms a conspicuous landmark on a hillside near North Harbour was roughly estimated to contain 24,000 cubic feet. All these sharply angular erratics I believe to have been stranded during the final dissolution of the ice-sheet.

I noticed no trace of any later local glaciation; neither terminal moraines nor mountain-valley rock-basins. Loch an Dun is probably excavated in rock; but it does not appear to be deep, and seems to be of the same character as those shallow lakes of Lewis, Harris, &c. which owe their origin to the erosive action of the ice-sheet, favoured by the configuration of the ground.

X. Islands south of Barra.

The only island south of Barra that we landed upon was Bearnareidh; but being favoured with beautiful weather we boated along the others sufficiently near to determine the strike and dip of the gneiss and the direction of glaciation.

1. *Bhaterseidh* (Vatersey).—This island is separated by a narrow and shallow channel from Barra. The highest point is not much more than 600 feet. The hill-face immediately opposite Barra is well glaciated, and the other hills appear to be not less well smoothed off. Good *roches moutonnées* are seen at the south-east corner of the island, just as one turns in from the south to Bhaterseidh Bay. The upper part of the hills is somewhat bare, but the lower grounds are well clothed with grass. There is much sand at

the head of Bhaterseidh Bay; in fact it forms an isthmus there connecting the north and south portions of the island, which have evidently at one time formed two separate islets. There is also much sand along the shores of Bhaterseidh Sound. Near the point on the north shore of Bhaterseidh Bay till is seen capping the gneiss and hugging the low shore. A low cliff on the southern shore of the bay seemed also to be composed of till; but we did not get near enough to be sure of this. The dip of the gneiss in the north-east of the island is south-east and east.

2. *Maoldomhnuich* (Maoldonuich).—This islet consists of a single hill, rising 500 feet above the sea. The dip of the gneiss is easterly, the lines of the bedding being marked out by grooves in which the grass grows comparatively thick and close. Two deeper and broader grooves or hollows run across the strike, and are in the same way marked out by vivid green, which contrasts strongly with the bare grey rock on either side. The hill is *moutonnée* all over.

3. *Saundreidh* (Saundrey).—The dip and strike of the gneiss are very conspicuous in this island, the dip being to north-east at angles varying from 20° to 60°. The gneiss is much jointed. Dykes of basalt are conspicuous in the sea-cliffs of the south-east. A sandy beach extends between Sgeir Leacnis and Eilean-mor. The sand is blown well up on the island, and gives rise, as usual, to a bright green grassy covering. The highest point of the island is 660 feet above the sea. No drift and very few erratics could be seen; but the whole island was well glaciated, and distinctly smoothed off from the south-east. The higher parts of the island are sparsely clothed with grass, which grows chiefly in the joints and hollows of the gneiss, and marks out long flutings or hollows that traverse the island from shore to shore along the line of strike. The most conspicuous of these hollows is traversed by two little brooks, flowing in opposite directions, one to north-west and the other to south-east.

4. *Flodeidh* (Flodey) is a low-lying flat islet, with grassy top.

5. *Lingeidh* (Lingey) has a rounded top, and presents steep cliffs to the south-west. The dip of the gneiss is towards north-east. The upper part of the cliff appeared bevelled off in a characteristic glacial manner. No drift and no erratics were visible.

6. *Grianamal* is a mere rock, in which the same dip as in Lingeidh occurs. No drift and no erratics were seen.

7. *Papeidh* (Papey).—The gneiss in this island dips north-east at angles ranging from 15° to 30°. The cliffs at the south-western extremity are smoothed off or bevelled along the summit by glacial action. The hill occupying the south-westerly end of the island is very bare, and finely *moutonnée* from south-east to north-west. A bay in the south-east shows a sandy beach, and the sand blown into the island affords soil which covers the barren rock and nourishes the usual bright green grass. The rest of the island is bare and paved with ice-smoothed rock-faces, in the interstices of which appears a scanty vegetation. The peninsula of Rudh Roisnis is absolutely naked: no soil, no drift, and no erratics were visible. Papeidh is 550 feet high.

8. *Miuleidh* (Miuley) shows well-rounded hills that rise to a height of 880 feet. They are somewhat greener than the hills of the other islands immediately to the north. The gneiss appears to be a good deal broken up; but along the south coast the hill-face is well smoothed and polished in the direction of the Sound of Bearnareidh. Till was seen on the shore at Sloc Chreimisgeo. The dip of the gneiss is north-east and east, the west coast being one great cliff nearly on the line of strike.

9. *Bearnareidh* (Bearnarey).—This island attains a height of 630 feet, and is tolerably well clothed with grass. The highest part is the ridge that runs along the south coast; from this the ground slopes steeply down to the Sound of Bearnareidh. Cliffs 600 feet high, and nearly vertical form the southern shore. The dip and strike of the gneiss are the same as in the adjoining islands. We landed on Bearnareidh, and spent some time in examining the glacial phenomena. Near the Storehouse and along the road, and for some distance up the hill across the face of which the road winds, are finely smoothed rock-faces, on some of which the striæ are well seen. I noted seven or eight surfaces of this kind. Frequently, however, the rock has "skinned," and only the deeper ruts, and sometimes not even these, are visible. The several bearings I took varied from W. 30° N. to W. 35° N., the striæ and *roches moutonnées* evidently pointing *to*, and not away from, that direction. Along the ridge of the island the gneiss crops up in broken ledges, which are distinctly bevelled off by glacial action, but the striæ have not been preserved. Mr. Campbell mentions the occurrence of ice-marks bearing N.N.W. magnetic, "crossing the strike of the rock on a 'tor' near the old fort," at Barra Head. We searched every face of rock at Barra Head for these marks, but were not fortunate enough to find them. The rocks thereabouts, however, are clearly glaciated; but their surfaces have scaled off or mouldered away, and the striæ have consequently disappeared. There is a boss of rock behind the lighthouse which is ice-worn, and may be the one referred to by Mr. Campbell; but although we had an exceptionally bright day, we could not make out even the "ghosts of scratches" upon its surface. That surface is certainly weathered. Many loose boulders and blocks are scattered over the ridge, and some of them are glacially abraded. Not a few, however, looked as if they had been wedged off the ledges of gneiss by human agency. Many, at all events, have been used to mark out the boundaries of fields at some distant period, for they are ranged in rows all over the hill-top, some slabs still standing erect and others now lying prone. On the lower slopes of the island a thin sprinkling of till occurs here and there.

XI. General Remarks on the Physical Features of the Long Island.

In traversing the Long Island from the Butt of Lewis to Barra Head, one cannot fail to observe that there are two separate elements which have combined to produce the present configuration of the surface. The glaciated outline is superimposed on an older set of features, which in the main appear to have been the result of ordinary atmospheric and aqueous erosion guided by the structural peculiarities of the rock. In my remarks upon the physical features of the islands, frequent reference has been made to the fact that the strike and dip of the gneiss have greatly influenced the conformation of the ground. And this, of course, is only natural, and what we usually expect to find. Long before the ice-sheet overflowed the Hebrides, the surface of those islands was marked in many places by escarpments and intervening hollows that traversed the land precisely in the line of strike. This latter being generally north-west and south-east, we find that such also is the prevailing trend of the features referred to. We see this notably in the district of Pairc or Park, and the neighbourhood of Loch Roag in Lewis, and throughout the larger portion of the whole Long Island; and the direction of most of the sounds and channels, and of the great majority of the sea-lochs, is the same. All these features, there can be little doubt, owe their origin to the long-continued action of ordinary subaerial denudation; even the hollows through which the sea now ebbs and flows probably came into existence at a time when the whole of these islands stood at a greater elevation above the sea. At present, indeed, the sea, instead of eroding, is silting-up the channels between the various islands. This is sufficiently proved by the presence of great shoals of sand, which, in the case of the North and South Fords, connect Benbecula at low water with North and South Uist.

Severe also as the glaciation of the Hebrides has been, we cannot attribute the transverse hollows exclusively to the action of the ice-sheet. Indeed it is impossible not to see that the features in question date their origin, as I have said, to preglacial times; for they do not always coincide in direction with the trend of the glaciation. Thus to the west of Stornoway the escarpments and intervening depressions run nearly at right angles to the glaciation; and the same appearance may be seen in some of the islands further south, particularly in South Uist.

The ice-sheet, therefore, only modified, and did not originate, the peculiar transverse ridges and hollows that characterize so large a portion of the Long Island. But the "modification" was somewhat extreme. Sharp-rimmed escarpments were smoothed off, and when the glaciation coincided, as it so frequently did, with the strike of the gneiss, the long transverse hollows were deepened and widened. That all, or nearly all, the lakes in the Long Island were likewise the proximate result of glaciation I have endeavoured to show, so that some of the most characteristic scenic features of the Outer Hebrides were due to the action of the ice-sheet.

XII. Summary of Results and Conclusion.

1. *Primary or General Glaciation.*—The evidence now brought forward demonstrates that the extent and thickness of the ice-sheet that buried Western Scotland during the climax of the glacial period was much greater than geologists have hitherto supposed.

It has been shown that the whole of the Long Island from the Butt of Lewis to Barra Head has been overflowed from the Minch by ice that moved outwards from the Inner Islands and the mainland, and the actual thickness of this ice-sheet it is now possible to measure with some approach to exactness. We have seen that the only points in the Outer Hebrides which have escaped glaciation are those that exceed a height of 1600 feet. Taking this, therefore, as the thickness of the ice that overflowed the lowest ground of the Long Island, and 3000 feet as the probable upper limits of the ice-sheet in Western Ross and Sutherland, we readily arrive at the depth of the ice-sheet that filled up the Minch. Immediately off the east coast of Harris the thickness of the ice would be upwards of 2300 feet; for the sea has a depth there of 121 fathoms. In the centre of the North Minch the upper surface of the *mer de glace* would be 2300 feet above what is now the sea-level, the actual thickness of the ice being 2700 feet. Nearer the shores of the mainland, in the Inner Sound, the depth attained by the ice would be still greater, no less than 3700 feet. Measuring from the Cliseam in North Harris to the mountains of Torridon, we have a distance of 56 miles, so that the inclination of the surface of the *mer de glace* was very little, the fall not being more than 1400 feet, or about 1 in 211. But slight as that incline was, it was probably twice as great as the slope of the *mer de glace* that filled up the German Ocean. Of course no one can believe that such enormous masses of ice could ever have been nourished by the snowfields of the mainland alone. The thickness attained clearly points to excessive precipitation over the whole area covered by the *mer de glace*; and we may be allowed to suppose that the ice was probably of the same peculiar laminated structure as that underneath which the Antarctic lands lie buried.

If the surface of the *mer de glace* continued to fall at the same rate, we should find marks of glaciation in St. Kilda up to a height of about 200 feet; whether this is actually the case I hope to ascertain at an early opportunity. But whether it be so or not, it is clear that the facts brought forward in this and the preceding paper completely negative the notion of a great Atlantic glacier, which it has been supposed flowed in upon Scotland.

It may have occurred to some as a difficulty that the *moraine profonde*, or till, of the ice-sheet contains so very few stones that do not occur *in situ* in the Outer Hebrides. If the ice actually flowed from the mainland and Skye across the Minch and over the Long Island, why should not many recognizable Skye rocks occur in the Hebridean till? The explanation appears to be as follows:—We must remember that although the upper surface of the ice-sheet flowed steadily towards the north-west, yet the bottom portion in the Minch would move in quite a different direction. The lower strata that impinged upon the foot-slopes of the Long Island, which are now below water, would be deflected to right and left, and two under-currents would set along the bottom of the Minch, one flowing north-east and the other south-west. These currents being due to obstruction would exert excessive erosive action upon the bed of the sea, and this would eventually result in the formation of deep rock-basins having the same trend as the present coast-line of the Outer Hebrides. Now, as I have pointed out elsewhere*, such a set of rock-basins does actually exist in the very position which, from theoretical considerations, they ought to occupy. Such being the course followed by the under portions of the *mer de glace* in the Minch, it is evident that the *débris* dragged on underneath the ice would be rolled north-east and south-west along the bottom of the Minch, and would thus never invade the Outer Hebrides at all. Now and then a few boulders might be pushed beyond the reach of the under-currents, and these would be dragged over the Long Island; but this would be quite exceptional, and hence we need not be surprised at finding only an occasional stranger from Skye or the mainland in the till of the Outer Hebrides.

Again, the very general absence of large angular erratics and perched blocks, derived from the lands beyond the Minch, is quite what we should expect. When the ice-sheet reached its greatest development, the Long Island was all but completely buried, only a few insignificant points in Harris and South Uist projecting above the surface of the *mer de glace*. So that the chances that any superficial erratics, travelling outwards from Skye or the mainland, should be caught on the tips of the Cliseam, or Beinn-mhor, or Hecla, were exceedingly small. The absence of such large angular erratics in the Outer Hebrides we may therefore look upon as an additional proof of the great depth attained by the ice that overflowed these islands.

By far the larger number of erratics which are found lying loose at the surface must belong to the later stages of the glacial period, most of them having been stranded during the gradual dissolution of the ice-sheet, while others are the relics of local snowfields and glaciers. Consequently they need not have travelled any distance. Each cliff and mountain-top, as it appeared, would begin to break up under the influence of frosts much more intense than are now experienced in our islands; and thus numbers of large angular blocks and heaps of *débris* would be supplied to the surface of the dissolving ice. And this morainic rubbish would eventually be scattered over the islands, most abundantly in the hilly districts, and less plentifully over the low grounds at a distance from the mountains.

2. *Shelly Boulder-clays and Interglacial Beds.*—It is very remarkable that shelly boulder-clays occur nowhere in the Long Island, save only upon the low grounds in the extreme north of Lewis. I searched for them everywhere, but without finding a single trace in any of the islands further south. For this peculiar restriction of their range there must be some reason; and the explanation, as it seems to me, is not far to seek. I have shown how the general absence from the unfossiliferous till of erratics from Skye and the mainland is to be accounted for by the deflection of the lower strata of the ice-sheet at the bottom of the Minch. Two under-currents of

* 'Great Ice Age,' second edition, p. 286.

ice set along the inner margin of the Long Island, one to south-west, the other to north-east. Now it is evident that these currents would eventually sweep round the obstruction caused by the great Hebridean ridge, and thereafter continue in the general direction of the ice-flow. If we examine the Admiralty charts of the Minch, we shall find that the ridge in question presents a steep face to the east, from a point opposite the Eye Peninsula to another point which lies 15 miles south of Barra Head. North of Eye Peninsula the sea-bottom rises with a gentle gradient to the coast of Lewis, so that there was nothing here to prevent the north-east under-current creeping up and over the low ground near the Butt. Let us note further that the most northerly rock-basin of any importance along the inner margin of the Long Island occurs just opposite the Eye Peninsula. Beyond this point the under-current met with little or no obstruction, and it ceased therefore to exert the same degree of erosion upon the sea-bottom. It now gradually turned away north and north-west, following the trend of the ridge, until—always creeping more and more to the west—it at last overflowed the northern end of Lewis. As its course lay along what had only recently been the sea-bottom, its *moraine profonde* necessarily contained shells and other marine exuviæ, and a much more considerable admixture of silt and clay than the unfossiliferous till throughout the rest of the Outer Hebrides.

No shelly boulder-clay occurs at the southern termination of the Long Island. But a glance at the Admiralty charts at once explains its absence. The steep ridge of rock that opposed the passage of the *mer de glace* continues, as I have said, to a point 15 miles south of Barra Head. Here the great Hebridean ridge terminates, and here the under-current of the ice was first enabled to change its direction and flow westward, its course being mapped out on the sea-bottom by the broad hollows it scooped out. It is evident, therefore, that, as the ice at the bottom of the Minch could not invade Barra and the islands to the south, no shelly boulder-clay would be pushed over any part of the ridge that now remains above water.

The interglacial deposits indicate a considerable change of climate; the ice-sheet which had overflowed the Long Island had now vanished, so far as the Outer Hebrides were concerned, and the sea once more occupied the Minch and rose to a height of 175 feet at least above its present level. The actual limits of submergence we cannot tell, for the reasons that follow; neither can we make any definite statement as to the character of the interglacial climate. The deposits are mere fragments, and their full meaning will probably not be realized until they are viewed in connexion with what is known of interglacial deposits in other regions.

In the Upper shelly Boulder-clay we read the return of precisely the same conditions as those that witnessed the accumulation of the Lower. The ice-sheet again overflowed the Long Island, and its under-current stole over the Butt as before. The interglacial beds were now subjected to much denudation. We can hardly doubt that they must at one time have occupied very considerable areas, not only in Lewis, but in the low-lying districts of the other islands to the south; for it is hardly conceivable that the interglacial submergence of 175 feet was confined to Northern and Eastern Lewis. The only portions, however, that now remain are the small patches at Garrabost and near the Butt. In no other part of the Long Island did I find any trace of them, although I was continually on the look-out. Yet it is by no means improbable that, could we obtain good sections across the low flats of North and South Uist, patches of them might be obtained here and there underlying and probably overlying till. The interrupted and patchy nature of the interglacial beds, and their remarkable absence from so much of the low grounds, where they cannot but have at one time existed, are undoubtedly due to the erosive action of the latest ice-sheet, which, like the ice-sheets of earlier glacial periods, made a nearly clean sweep of the Hebridean ridge, leaving patches of the earlier deposits in sheltered nooks, and sparing them to some extent in areas where the ice had freedom to flow in one broad uninterrupted stream, and where consequently its erosive action was not so great.

Before I had examined the glacial phenomena of the southern islands of the Outer Hebrides I was hardly prepared to believe that the latest ice-sheet attained so great a development. It seems, however, impossible now to resist the conclusion that the last *mer de glace*—that, namely, which cut out the interglacial deposits—actually overwhelmed the whole Outer Hebrides. Whether it reached to as great a height as the earlier ice-sheet, whose *moraine profonde* is represented by the Lower shelly Boulder-clay, I cannot say; but it is possible that a minute examination of the evidence, and careful mapping-out of all the details, may eventually enable us to settle this point. It is possible also that we may yet obtain evidence to show that there were more than two incursions of the *mer de glace*. We know, indeed, from the facts supplied in other parts of the country, that there really were more than two cold periods. But unfortunately the records of the earlier phases of the glacial epoch are always more or less fragmentary; and in a region like that under review we cannot expect to meet with early glacial and interglacial deposits in such abundance as in lower latitudes, and in places where there was less obstruction to the flow of the ice. As it is, we must look upon all the unfossiliferous till and morainic *débris* of the Long Island as pertaining to the incursion of the latest ice-sheet, although much of it may be merely that of earlier ice-periods reworked and redistributed.

3. *Local Glaciers.*—While the latest ice-sheet slowly melted away, local ice was enabled to flow down the valleys in all directions. At first these local glaciers coalesced with the general *mer de glace*; but eventually this connexion was severed, and many of them continued to exist probably to late glacial times, to that period, namely, which is represented on the mainland of Scotland by those shelly clays which are found resting upon the youngest accumulations of boulder-clay. None of these local glaciers, in their independent condition,

was of any size, as one may judge not only from the position of their moraines, but from the size of the valleys and the capacity of the feeding-grounds.

In leaving the subject of glaciation, a word or two may be added on the very notable absence of kames. Not a trace of these was met with between the Butt and Barra Head. All this is quite in keeping with the view that our kames owe their origin to torrential waters flowing under and upon, and escaping at the margins of, the melting *mer de glace*. Their remarkable distribution on the mainland of Scotland shows that this was their origin; they were deposited and heaped up by water flowing from higher to lower levels. Hence their contents become finer-grained and better waterworn the further they are traced from their sources. In the lower reaches of our broad valleys they are generally composed of well-bedded sand and water-worn gravel; in the upper parts of the valleys they are not so well bedded, and their materials are generally much coarser. Traced nearer to the mountains, they gradually pass into irregular spreads and heaps of morainic gravels and *débris*. Now the broad flats of Lewis would not be traversed during the melting of the ice-sheet by any great diluvial torrents; for none of the large valleys opens to the north. Nor is the configuration of the ground in South Lewis and Harris a whit more favourable. The valleys are short and steep, and not such as kames are ever found in. We get the coarse morainic gravel and *débris*; but those materials have not travelled far enough to be sufficiently water-worn, and the valleys are too narrow and steep to permit the heaping up of banks of such incoherent materials. It is precisely the same with the other islands of the Outer Hebrides. The conditions for the formation of kames did not exist in the Long Island any more than in the upper and central part of any mountain district of the Northern Highlands. If kames were formed by diluvial torrents derived from the melting of the Hebridean ice, they probably now lie submerged at a considerable distance from the land, where they will occupy the same position relatively to the mountainous Hebrides as the kames of the Lowlands do to the Highlands and Southern Uplands. Judging from all analogy, indeed, one can hardly doubt that the submarine plateau which extends beyond the Outer Hebrides to the 100-fathom line must be more or less plentifully covered with drift sand and gravel, laid down during the final retreat of the *mer de glace*. And I am thus led to believe that much of the sand which is driven in such vast quantities chiefly upon the western shores of the Outer Hebrides, and which is gradually silting up the channels between the various islands, is derived from drift-deposits corresponding in nature and origin to the great diluvial sands of Northern Germany.

4. *Postglacial or recent submergence.*—In concluding, I would draw attention to the striking fact that there has been no considerable submergence of the Long Island since the close of the last glacial period. No high-level beaches occur anywhere. No trace of any undoubted postglacial occupation by the sea is found above a

height of 80 feet. At the Butt some shelly sand, which appears to be of aqueous origin, overlies the glacial deposits, and reaches to a height of 80 feet or so above the sea. It is just possible, however, that this accumulation may be merely a rearranged portion of the fossiliferous glacial beds; at all events, no recent marine deposit attained an equal elevation in any of the islands. Shelly sands do occur at higher levels, especially in the little islands south of Barra; but these are simply blown in by the strong westerly winds from the sandy beaches, the shelly materials consisting chiefly of finely comminuted fragments of the common cockle. What appear to be old sea-levels occur along the shores of West Loch Tarbert, and here and there upon the west coasts of several of the islands; but none of these reaches higher than a dozen feet or so above the sea; and I should have been surer of their marine origin had I found beach-deposits resting upon them, but I was not so fortunate. Nevertheless one can hardly doubt that much of the low flat ground that borders on the Atlantic has been reclaimed from the sea in postglacial times. The absence of recent marine deposits at high levels has struck me also in not a few of the islands of the Inner Hebrides, the raised beaches which I have seen occurring mostly below a height of 100 feet above the present sea-level. From the aspect presented by some of these "raised beaches," they seemed to indicate no long persistent submergence, but rather to have been the result of storm-waves. Not unfrequently they occur on low spits of land exposed to the full swell of the Atlantic, and they appear also upon the borders of narrow bays facing in the same manner the open sea. Along the steeper shores of the same islands, however, one usually looked in vain for ledges excavated in the solid rock at levels corresponding to those occupied by the shingle-beds or raised beaches, and the most distinct ledges occur at low levels. According to my colleague, Mr. J. Horne, there is a similar absence in the Shetland Islands of high-level recent marine deposits, and my brother has shown that this is likewise true of the Orkneys. Although very much has been done towards working out the history of the postglacial submergence of Scotland, there is yet a great deal more to be learned, and not a little, as I believe, to be unlearned. At present we have no evidence to indicate that the mainland of Scotland experienced a greater degree of submergence in postglacial times than 100 feet. The marine deposits at higher levels than this belong, as I have brought forward evidence to show, not to postglacial, but to interglacial times.

At various points along the shores of the Long Island occur beds of peat, with remains of trees, in positions which prove that these outer islands in late postglacial and recent times were of larger dimensions than now. Precisely the same phenomena reappear on the opposite coasts of the mainland, as geologists have long been aware.

Note.

In the discussion that followed the reading of this paper, Professor Judd is reported to have said that erratics derived from the western islands occur upon the mainland. I suppose Mr. Judd refers to some large blocks of a dark gabbro which are found in the vicinity of Loch Creran, and which are similar in character to the gabbro of Mull. But Mull is not the only place in Scotland where gabbro occurs; and for many reasons, which need not be pointed out here, it is in the highest degree unlikely that the Loch-Creran erratics came from that island. Their parent rock will probably be found in Dalness Forest or the heights above Glencoe. I have never seen upon the mainland any erratics which could be shown to have come from the Inner or Outer Hebrides; but it is quite possible that such may yet be detected at low levels—in such districts, namely, as were submerged in late glacial times.

September, 1878.

EXPLANATION OF PLATE XXXIII.

Map of the Outer Hebrides and the Minch, showing the direction of glaciation and the position of submerged rock-basins. The soundings are from the Admiralty charts; but these are given only in sufficient numbers to indicate the general configuration of the sea-bottom.

Discussion*.

The President called attention to a point not noticed by the authors who had dealt with changes of climate, namely, that we are not justified in assuming that the amount of heat given out by the sun in past times has been always the same. It was quite possible that it might have varied; and this should be borne in mind in all speculations on the subject.

Mr. J. F. Campbell confined his remarks chiefly to the first paper, as he did not believe in general glacial periods. As there are terraces on the banks of the Nile, marking water-levels half a year old, so in Britain and Western Europe terraces and shells prove that the sea has stood 1200 feet higher: at different levels tides would carry floating ice to and fro in channels, so as to score rocks. The arrows in Mr. Geikie's Map of the Hebrides point in all directions. Whence ice came to score certain rocks to which Mr. Campbell referred in a former paper, was another question. He had suggested from the N.W.; Mr. Geikie has said from S.E. The rocks of

* This discussion related to two other papers read the same evening, but which have since been withdrawn. These were entitled, "Cataclysmic Theories of Geological Climate," by Dr. James Croll (now published in the 'Geological Magazine' for Sept. 1878), and "On the Distribution of Ice during the Glacial Period," by T. F. Jamieson, Esq., F.G.S.

Skye and N. Uist differ conspicuously. There are very few erratics in the Outer Hebrides; very few N. Uist erratics in Skye. Probably the movement of ice afloat coincided with that of tides, and was from the north rather than from the south.

Mr. BELT thought that the evidence on which Mr. Geikie had founded his conclusion that the ice that had glaciated the Outer Hebrides came from the south-east was unsatisfactory, and that some of it actually pointed to the opposite opinion. That more till had been left on the west sides of the islands than on the east was inconsistent with the idea that the ice had come from the latter direction. During the increase and greatest extension of the ice it would polish and score the rocks below it, and it was during its retreat that it would leave behind it the detritus it had gathered into its mass. As it melted back, the mud and stones would be deposited on slopes opposed to its course, as there the water issuing from the retreating glacier would be pounded back; whilst on the slopes coinciding with its flow the water would find a free outlet, and carry away the mud, as it does now in the Swiss glaciers.

The hills of Skye lay directly in the course of the supposed flow of ice from the mainland, and their rocks should have been largely represented in the boulders of the Outer Hebrides on Mr. Geikie's theory, but they were entirely absent. Even if the ice at one time passed completely over the Outer Hebrides, a time would come in its retrocession when it ought to have left its terminal moraine there, and in this the rocks of Skye should have abounded. Their absence seemed to be fatal to the theory brought before them.

He objected to the notion that the lower portion of the ice-flow could have moved at right angles to that invading and overflowing the Hebrides. If there was an outlet for the deepest portion of the ice to the south-west, there must also have been one in the same direction for the upper portion, and no reason would exist for the persistent flow of the ice over the whole of the Hebrides in a north-west and south-east line.

The DUKE OF ARGYLL referred to the glacial phenomena of the Inner Hebrides and the mainland, and said that from these he was led entirely to disbelieve in the theory of an ice-sheet, not because he did not believe in a "glacial period," that is, that there had formerly been a great extension of ice where now there is none. All the phenomena he had seen could be accounted for by the action of glaciers and of floating ice. All over the Highlands there were on the hills, up to 1400 or 1500 feet, perched boulders, not rounded or scratched, proving, he thought, a submergence to that extent. These, he thought, could not be explained by an ice-sheet. They generally rested on exposed knolls and prominences, and could only be accounted for by assuming the agency of ice-rafts loaded with rocks. Now if there were a gradual rising and sinking of the land, the whole surface would be glaciated. He thought that a Palæocrystic sea would give all the conditions required for the glaciation of the Highlands. We have no proof of ice being able to walk up and down hill, as the advocates of an ice-sheet required it to do. If Greenland, as had been asserted, was covered with an ice-sheet, surely this would be able to cross the narrow strait separating that country from the American continent; but it appeared that Greenland really had only enormous glaciers, which did not cross the strait. We can, indeed, theorize as to the conditions prevailing in the Antarctic region, because we know little or nothing about them; still it was to be observed that, while the Arctic icebergs are very irregular in form, the Antarctic ones are flat-topped. The former are fragments of glaciers, hence their form; the latter had not been strained, and so showed that they were not derived from a sheet moving over the southern continent. He doubted whether there was any physical evidence to prove that ice could move to the extent required on a slope of 1 in 211, or indeed of 1 in 422; in such a case he regarded it as impossible that gravitation could produce motion. The absence of fragments from the mainland and Inner Hebrides upon the Outer Hebrides seemed to him to show that no great body of ice could have passed from the former to the latter. The formation of Boulder-clay was probably effected in shallow water by floating ice.

Prof. Ramsay thought that the idea of local precipitation favouring glacial action, though not new, had been remarkably well treated by Mr. Jamieson. The notion of the existence of two great ice-sheets, once put forward by Agassiz, would not, he thought, be again seriously advanced. At the same time, he did not think that floating ice and comparatively small glaciers would explain the phenomena recorded by Mr. Geikie along all the western side of Scotland above the sea and below it. In his opinion, glacier ice did not move by gravitation alone; its behaviour was, so to speak, more like that of sluggish water. The marks, as a rule, follow the general trend of the valleys, though there might be local variations, and the direction of glaciers could be inferred from the markings. He thought that there was good evidence that large districts of Scotland, England, and Ireland had been covered by land-ice, and he quite accepted Mr. Geikie's conclusions as to the thickness of the ice. He had himself found it 1300 feet in the Llanberis valley. He called attention to the rock-basins between the mainland and the Hebrides being just where his theory of excavation would require them to be, paralleling the case of the lakes in the Alps and at the foot of the Jura. If a great quantity of ice accumulated in the interior of a district it would flow outwards.

Prof. Judd stated that, while boulders derived from Skye, Rum, Mull, &c., did not go to the Outer Hebrides, and on Skye rocks from the mainland are very rare, yet boulders derived from the Inner Hebrides are certainly found on the west coast of Scotland.

Mr. Callard remarked that, if Mr. Croll's theory were true, we ought to find evidence of the glaciation of the planet Mars at the present time. But such was not the case, so he doubted the correctness of the theory. Referring to the President's remarks, he said that there was evidence of change in the photospheres of other stars, so that we might infer the occurrence of similar changes in that of the sun.

Prof. Boyd Dawkins objected to Mr. Croll's theory of the recurrence of glacial periods that the palæontological evidence was all the other way.

Prof. Seeley pointed out that the level of the land in the west of Scotland might have been different from what it is now, and Boulder-clay &c. might have been removed, so that the objection from the absence of rock-fragments was perhaps not insuperable.

THE OUTER HEBRIDES AND THE MINCH.
Glacial Striæ
Roches moutonnées (indicated in only a few places where striæ were not seen.)
Long red arrows show the course followed by under-currents of Ice-sheet.
Submerged Rock-basins coloured blue.
Soundings in fathoms, from Admiralty Charts
Dip of Gneiss under 65°
above 65°
Vertical strata
Horizontal
English Miles.
LEWIS
NORTH MINCH
Stornoway
Butt of Lewis
LITTLE MINCH
North Uist
Benbecula
South Uist
ISLE OF SKYE
Sound of Harris
Raasay
Rum I.
Canna I.
Muck I.
Eigg I.
Coll I.
Tyree I.
Staffa
Ulva
Tobermory
Ardnamurchan
MULL
Sleat

50. *On some well-defined* Life-zones *in the Lower Part of the* Silurian (*Sedgwick*) *of the* Lake-district. By J. E. Marr, Esq., Scholar of St. John's College, Cambridge. (Read June 19, 1878.)

[Communicated by Prof. T. McKenny Hughes, M.A., F.G.S.]

The following paper treats of the different zones of fossils occurring in the strata between the Coniston Limestone and the Coniston Grits of the Lake-district, with the view of correlating the beds in the more central part of the district with those of the outlying districts in the neighbourhood of the Pennine chain, and of establishing the position of the boundary between the Cambrian and Silurian formations. This boundary, as indicated by the palæontological evidence, coincides with the position already assigned to it by Prof. Hughes, from the study of the district east of the river Lune (Geol. Mag. vol. iv. no. 8).

A marked feature in the fauna of the Lake-district beds of these formations is the frequent occurrence of the genus *Phacops* at different horizons, each fossiliferous formation being characterized by one or more species of its different subgenera, as seen in the following list:—

Formation.	Characteristic *Phacops*.
Kirkby-Moor Flags ...	*Phacops* (*Odontochile*) *caudatus*, var. *minor*, and *Ph.* (*Acaste*) *Downingiæ*.
Bannisdale Slates	*Phacops* (*Acaste*) *Downingiæ*.
Coniston Grits	*Phacops* (*Acaste*) *Downingiæ*.
Coniston Flags	*Phacops* (*Odontochile*) *obtusicaudatus*.
Stockdale Shales	*Phacops* (proper), sp.
Ashgill Shales	*Phacops* (*Odontochile*) *mucronatus*, var., and *Ph.* (*Acaste*) *apiculatus*.
Coniston Limestone ...	*Phacops* (*Chasmops*) *macroura*, and *Ph.* (*Chasmops*) *conophthalmus*.
Green Slates	(No fossils.)
Skiddaw Slates	*Phacops* (*Acaste*) *Nicholsoni*.

The zones marked by these species of *Phacops* will be found to hold good when the organic remains as a whole are considered.

Beginning at the lower beds, the Skiddaw Slates and Green Slates have already been fully treated of by many geologists, notably by Profs. Harkness and Nicholson, and the Coniston Limestone has also been admirably described by the same authors; but a series of beds has been included in this formation, which I hope to show, both on palæontological and stratigraphical grounds, should be cut off from it as a distinct subdivision. If these beds be so dealt with, it will cause some little modification in all the lists of the Coniston-Limestone fossils hitherto published, except that given by Prof. Hughes in the above-mentioned paper, in which the two formations are locally distinguished and separate fossil lists given.

1. Coniston Limestone.

I have nothing to add to the excellent description given by Profs. Harkness and Nicholson of this formation (Quart. Journ. Geol. Soc. vol. xxxiii. p. 464), but give a revised list of the fossils of the formation, compiled from the specimens in the Woodwardian Museum, Cambridge, the Museum of Practical Geology, Jermyn Street, and in my own collection.

Fossils of the Coniston Limestone.

Actinozoa.

Heliolites interstinctus, *Wahl.*	Coniston; Sunny Brow; Applethwaite Common; Long Sleddale.
H. subtubulatus, *M'Coy*	Sunny Brow; Coniston.
H. tubulatus, *Lonsd.*	Coniston.
H., sp.	Barking, Dent.
H. megastoma, *M'Coy*	High Haume; Coniston.
Favosites crassus, *M'Coy*	Coniston.
F. alveolaris, *Goldf.*	Dry Ridge, Horton.
F. fibrosus, *Goldf.*	Troutbeck; Coniston; Horton, &c.
F. fibrosus, var. lycoperdon, *Hall*	Coniston.
Nebulipora explanata, *M'Coy*	Coniston.
N. favulosa, *Phill.*	Applethwaite Common; Coniston.
N. papillata, *M'Coy*	Coniston.
Halysites catenularius, *Linn.*	Coniston; Applethwaite; Ingleton; Thornton.
H. catenularius, var. labyrinthica, *Linn.*	High Haume; Dalton-in-Furness.
Omphyma turbinata, *Linn.*	Coniston.
Sarcinula organum, *Linn.*	High Haume; Long Sleddale; Coniston.
Petraia æquisulcata, *M'Coy*	Coniston.
P., n. sp.	Troutbeck.
Cyathophyllum, sp.	Troutbeck.
Goniophyllum?	Helm Gill.

Polyzoa.

Berenicea heterogyra, *M'Coy*	Applethwaite Common; Coniston.
Ptilodictya dichotoma, *Portl.*	Coniston.
Pt. acuta?	Troutbeck.
Phyllopora Hisingeri, *M'Coy*	Coniston.

Echinodermata.

Echinosphærites Davisii, *M'Coy*	Troutbeck; Coniston.
E. balthicus	Troutbeck.
E. mammosus?	Troutbeck.

Annelida?

Tentaculites anglicus, *Salt.*	Ravenstonedale; Applethwaite Common.

Crustacea.

Primitia M'Coyi, *Salt. MS.*	Keisley; Dufton.
P. M'Coyi, var.	Pusgill; Dufton.
Beyrichia complicata, *Salt.*	Coniston.
B. strangulata, *Salt.*	Applethwaite Common; Coniston.
Harpes Doranni, *Portl.*	Coniston.
Trinucleus seticornis, *His.*	Dufton; Applethwaite Common.
Lichas laciniatus, *Dalm.*	Coniston.

Sphærexochus boops, *Salt.*	Applethwaite Common; Coniston.
Amphion, n. sp.	Troutbeck.
Cybele verrucosa, *Dalm.*	Horton; Ravenstonedale; Troutbeck Coniston.
C. rugosa, *Portl.*	Coniston.
Encrinurus multiplicatus, *Salt.*	Barking, Dent.
E. multisegmentatus	Helm Gill.
Cheirurus bimucronatus, *Murch.*	Near Dent.
Phacops macroura, *Sjögren*	Long Sleddale; Style End; Applethwaite Common; Coniston.
Ph. conophthalmus, *Bœck.*	Near Dent.
Ph. nitidus, *Salt.*	Helm Gill.
Calymene senaria, *Conr.*	Horton; High Haume; Applethwaite Common; Coniston.
Illænus Bowmanni, *Salt.*	Keisley.
I. Rosenbergi, *Eichw.*	Horton; Sunny Brow; Coniston.
Remopleurides	Near Dent.

MOLLUSCA.

Lingula ovata, *M'Coy*	Applethwaite Common; Coniston.
Trematis corona, *Salt.*	Pusgill; Dufton.
Rhynchonella, sp.	Ravenstonedale.
Orthis Actoniæ, *Sow.*	Ingleton; Horton; Thornton; Applethwaite Common, &c.
O. bidens, *Salt. MS.*	Helm Gill, Dent.
O. calligramma, var. plicata, *Salt.*	Horton.
O. calligramma, var. virgata, *Salt.*	Applethwaite Common; Coniston.
O. calligramma, var. crispa, *M'Coy*	Helm Gill, Dent.
O. flabellulum, *Sow.*	Applethwaite Common.
O. porcata, *M'Coy*	Coniston.
O. biforata, *Schloth.*	Troutbeck; Coniston.
O. insularis, *Eichw.*	Coniston.
O. vespertilio, *Sow.*	Coniston.
Strophomena antiquata, *Sow.*	Coniston.
S. corrugata, *Portl.*	Keisley.
S. depressa, *Dalm.*	Everywhere.
S. deltoidea, *Conr.*	Coniston.
S. pecten, *Linn.*	Ravenstonedale; Applethwaite Common; Coniston.
Leptæna transversalis, *Dalm.*	Coniston.
L. quinquecostata, *M'Coy*	Near Dent.
Orthonotus?	Applethwaite Common.
Holopella	Troutbeck Hundreds.
Holopea	Troutbeck Hundreds.
Orthoceras vagans, *Salt.*	Troutbeck; Coniston; Dufton.
O. sp., like Troostii	Troutbeck.
Cyrtoceras sonax, *Salt.*	Helm Gill.
Lituites cornu-arietis, *Sow.*	Troutbeck; Coniston.

2. ASHGILL SHALES.

The beds for which this name is adopted—from a stream near Coniston, where the beds are very well developed and have been spoken of by Salter (Cat. Cambr. & Sil. Foss. of Woodw. Mus. p. 72) under this name—have been, as already stated, separated locally by Prof. Hughes in the country to the east of the Lune, and occur, more or less developed, throughout the Lake-district.

On comparing specimens of this formation from the Windermere-district with others from the district east of the river Lune, it will be seen that they agree remarkably in lithological character, whereas they are totally different from any shales developed in the Coniston Limestone itself; and in specimens from Ashgill the same texture is observable, the only difference being that here the beds are much more strongly cleaved. These beds may be described as consisting of leaden-blue calcareous mudstone, of very fine texture, interbedded in places with pale green mudstones, the whole being affected by cleavage, so as to break up into prismatic fragments, which last peculiarity is very characteristic of the beds. They bear in places some resemblance to the lower division of the Coniston Flags, from which they may be distinguished generally by the total absence of the fine lamination so characteristic of the Coniston Flags.

On the east side of the Lune they are well seen in Spengill, Taiths Gill, Fairy Gill, &c. They are here of considerable thickness, and fossils are fairly abundant, especially *Strophomenæ,* one of which, *Strophomena siluriana*, Dav., occurs in great abundance in every locality where these beds are found, and has never been found in the underlying Coniston Limestone. *Phacops apiculatus*, occurring at Rother Bridge, is also characteristic of these beds. The beds here, as in other places, rest immediately and quite conformably upon the Coniston Limestone.

On following the beds from Shap along the line of strike, the Coniston Limestone is overlain for some distance by beds referred by us to the Silurian, the Ashgill Shales being absent until we reach Applethwaite Common, on the east side of Troutbeck. Here they appear, although extremely thin; but they possess all the characters of the beds in the district to the east of the Lune, except that they are much more highly fossiliferous. They are again met with on the west side of the great fault which runs down the Troutbeck valley, and may be traced across Scot Beck and Nanny Lane to the well-known section at Skelgill, becoming thicker in passing westward from Troutbeck to this place. The most abundant fossil is *Strophomena siluriana,* and at Nanny Lane and Skelgill several specimens of *Phacops mucronatus*, var., and *Phacops apiculatus* have occurred. The beds are next exposed in Pull Beck, on the west side of Windermere. At Ashgill, about three miles S.W. of Coniston, we find them magnificently exposed in a quarry and stream, in the former of which they have been worked for flags. They are here very thick, strongly cleaved, and fairly fossiliferous. They still contain *Strophomena siluriana* in abundance, though *Orthis protensa* is the predominant form, and *Phacops mucronatus*, var., and *Phacops apiculatus* also abound in places. The Ashgill beds are again found at Rebecca-Hill quarry, about three miles north of Dalton-in-Furness, where they possess the same lithological character and have the same fossils as at Windermere &c. These beds may be traced across the country, and distinguished from the Coniston Limestone by lithological characters only.

The following list of fossils will further indicate the palæontological differences :—

Fossils of the Ashgill Shales.

ACTINOZOA.

Petraia subduplicata, var. crenulata. Near Dent.

ECHINODERMATA.

Glyptocrinus	Troutbeck.
Echinosphærites	Ashgill.

ANNELIDA.

Cornulites	Nanny Lane, Troutbeck.

CRUSTACEA.

Phyllopods	Spengill; Skelgill.
Spines of do.	Spengill.
Trinucleus concentricus	Helm Gill &c.
Ogygia?	Scot Beck, Windermere.
Phacops apiculatus, *Salt.*	Rother Bridge; Nanny Lane; Skelgill; Ashgill.
Phacops mucronatus, *Brongn*, var.	Nanny Lane; Skelgill; Ashgill.
Phacops, sp. (not obtusicaudatus)	Sarly Beck, near Dent.
Phacops (sp. with long head-spines)	Scot Beck.
Calymene	Ashgill.

MOLLUSCA.

Lingula	Skelgill; Ashgill.
Rhynchonella	Rebecca Hill.
Orthis biforata, *Schloth.*	Near Dent; Skelgill; Ashgill.
O. protensa, *Sow.*	Skelgill; Ashgill; Rebecca Hill.
O. vespertilio, *Sow.*	Near Dent; Skelgill; Ashgill.
O. calligramma, *Dalm.*	Near Dent.
Strophomena siluriana, *Dav.*	Fairy Gill; Spengill; Applethwaite Common; Nanny Lane; Skelgill; Ashgill; Rebecca Hill.
S. depressa, *Dalm.*	Near Dent.
S. alternata	Near Dent.
S. (sp. with fine striæ)	Skelgill; Ashgill.
Bellerophon trilobatus?	Ashgill.

On comparing this list with that of the Coniston-Limestone fossils, it will be seen that only a few species are common to the two formations, and those are the very common Bala fossils, such as *Orthis vespertilio*; whilst the typical Ashgill-shale fossils, viz., *Phacops mucronatus*, var., *Phacops apiculatus, Orthis protensa*, and *Strophomena siluriana*, have not, to my knowledge, been yet found in the Coniston Limestone. The palæontological evidence, then, fully bears out the conclusion arrived at from lithological character and stratigraphical relations, that the Ashgill Shales should be viewed as a group distinct from the Coniston Limestone.

The fossils are all of Bala type, though some, as *Cornulites* and *Strophomena siluriana*, point to a rather higher horizon, and they bear out the conclusion of Salter (Cat. Cambr. & Sil. Foss. of Woodw. Mus. p. 72) that these beds are referable to the Upper Bala.

Another point of great interest in this series is its great irregularity of thickness, due either to unconformability or to overlap of the overlying series. It is impossible, in the present state of our knowledge, to ascertain with certainty to which this appearance is due, but there are some facts which point to unconformity. As we go from Troutbeck eastward, we find the Ashgill Shales rapidly thin out and disappear before reaching Kentmere. In Long Sleddale the Coniston Limestone itself is thin (leaving out of consideration the contemporaneous flows), and advancing towards Shap, disappears altogether. A fault is drawn by the Geological Survey to account for this; but it is impossible to say whether this is the case, or whether the whole of the limestone may not have been denuded, and the Silurian rocks deposited directly on the green slates.

Again, passing from Ashgill to Coniston, on reaching Torver Beck, about one mile N.E. of Ashgill, we find very little room for the Ashgill shales between the Coniston Limestone and the top of the Graptolitic mudstones. Unfortunately the section in this stream is interrupted; but as the swampy ground which occurs between the limestone and pale shales keeps the same position from Torver Beck nearly to Coniston Waterhead, we can hardly suppose it to be a line of fault, but merely a feature caused by the soft mudstones. If this be the case, the comparatively great thickness of shales represented in the Ashgill quarry has, in the space of about a mile, nearly or quite disappeared; this could scarcely be the result of overlap, but points to an unconformity.

The Ashgill shales are included in the Coniston-Limestone series of Mr. Aveline, which are considered by him to be covered unconformably by the Stockdale shales (see Geol. Mag. vol. ix. (1872), p. 441, and dec. ii. vol. iii. (1876) p. 282).

3. Basement-bed of the Silurian.

The position of the physical break between the Ashgill shales and the series above is marked in different localities by a bed partly composed of derived fragments, but differing much in lithological character. As Prof. Hughes has worked out these beds in detail, I merely give a list of fossils found in them.

Fossils of the Basement-bed.

Actinozoa.

Favosites	Horton, in Ribblesdale.
F. fibrosus	Spengill; Taith's Gill.

Crustacea.

Illænus?	Skelgill.

Annelida.

Cornulites	Spengill.

Mollusca.

Strophomena siluriana, *Dav.*	Spengill.
S. (sp. with fine striæ)	Skelgill.
Meristella crassa	Spengill.
Orthis	Taith's Gill; Skelgill.

This list is unfortunately very scanty; for fossils, though abundant in places, are generally much distorted. *Strophomena siluriana*, so abundant in the Ashgill shales, just comes up into this bed. *Meristella crassa* is a characteristic fossil of the May-Hill group.

4. Stockdale Shales (Aveline).

These beds are divided into three subdivisions, distinguishable by lithological character, viz. :—*a*. Lower, black shales; *b*. Middle, Graptolitic mudstones; *c*. Upper, pale shales.

a. The *Black Shales* are seen at Spengill, Ashgill, &c. They contain few organisms, the only ones I have yet seen being a crinoid and a species of *Strophomena* from Spengill.

b. *Graptolitic Mudstones* (Harkness & Nicholson).—These, as their name implies, are black mudstones full of Graptolites; but they contain interstratified non-Graptolitiferous flaggy beds, which, in places, as at Skelgill, are thicker than the mudstones themselves. Fossils other than Graptolites have been discovered by Profs. Harkness and Nicholson in these beds (Quart. Journ. Geol. Soc. vol. xxxiii. p. 473). The best section of these in the district is seen in Skelgill, at a footbridge near where the 800-feet contour-line crosses the stream, and a few hundred yards N.E. of the farm of High Skelgill.

The section seen here is given at p. 878 (fig. 1), drawn to true scale.

Fossils have been obtained from the beds marked P.Z., A.Z., and E.Z., respectively characterized by the occurrence in some abundance of a species of *Phacops*, *Monograptus argenteus*, and *Encrinurus variolaris*.

The following is a list of fossils other than Graptolites which I have obtained from the Graptolitic Mudstones and their associated flaggy and calcareous beds:—

Actinozoa.	
Petraia (small species)	Spengill; Skelgill (P.Z. & E.Z.).
Favosites asper?	Skelgill (P.Z.).
Crustacea.	
Entomostraca	Spengill; Skelgill (P.Z. & E.Z.), Torver Beck.
Large phyllopod	Skelgill (A.Z.).
Discinocaris Browniana, *Woodw.*	Skelgill (A.Z.).
Peltocaris aptychoides	West side of Long Sleddale.
Acidaspis (resembling species of Upper May-Hill beds, from Penlan, Llandovery)	Skelgill (E.Z.).
Acidaspis	Torver Beck.
Proetus Stokesii?	Skelgill (P.Z.).
Harpes	Skelgill (P.Z.).
Cheirurus bimucronatus, *Murch.*	Spengill; Skelgill (P.Z. & E.Z.).
Phacops (sp. with punctate margin to cheeks)	Skelgill (P.Z.).
Phacops (smaller species)	Spengill; Skelgill (P.Z.); Torver Beck.
Encrinurus variolaris, *Brong.*	Skelgill (E.Z.).
Calymene	Skelgill (P.Z.).
Illænus	Spengill.
Mollusca.	
Orthis (undeterminable)	Skelgill (P.Z.).
Leptæna quinquecostata, *M'Coy*	Spengill; Skelgill (E.Z.); Torver Beck.
Orthoceras	Skelgill (P.Z., A.Z., & E.Z.).

Fig. 1.—*Section at Lower Footbridge, Skelgill.*
(Scale 1 inch to 10 feet.)

		ft.	in.	
No. 12...	Light blue flags	11	0	seen.
No. 11...	Mudstones	2	0	
No. 10...	Blue flags	2	6	
No. 9...	Mudstones	0	8	
No. 8...	Blue flags	4	0	
No. 7...	Mudstones (*Graptolites convolutus*, var. *spiralis*, and *Diplograpsus tamariscus* at base)	6	6	
P.Z. ...	Blue flags, with bands of calcareous concretions =*Phacops*-zone	8	0	
A.Z. ...	*Argenteus*-mudstones	0	8	
E.Z....	Blue flags, with bands of calcareous concretions =*Encrinurus*-zone	4	0	
No. 3...	Mudstones	6	0	about.
No. 2...	Blue flaggy mudstones	3	0	about.
No. 1...	Mudstones, flaggy at base	6	0	
	Basement bed of Silurian	1	0	
	Ashgill shales. Total	55	4	

These fossils were found in every case in beds included between undoubted Graptolitic Mudstones. The position of the Skelgill fossils is indicated by the letters annexed to them, which refer to the zones in the section given. The fossils of Spengill and Torver Beck came from flaggy beds with calcareous concretions, passing in places into impure limestone, occurring in each case near the top of the Graptolitic Mudstones. Lastly, the *Peltocaris* from Long Sleddale was found in the midst of the Graptolitic bands.

On looking at the list, more especially that of the Crustacea, we are at once struck with the Silurian facies of the genera. *Acidaspis*, *Proetus*, *Harpes*, and *Encrinurus* are genera never occurring as the characteristic Trilobites of even the highest beds of the Cambrian series; and I can find no instance where they occur associated in abundance in that series, as is the case in the Graptolitic Mudstones. On the other hand, such Trilobites as *Trinucleus*, *Lichas*, *Cybele*, *Asaphus*, and the large species of *Phacops* of the subgenus *Chasmops*, so typical of the Bala beds, are totally absent from this list. The *Phacopes* present, probably referable to two species, both belong to the subgenus *Phacops* proper, which I cannot find recorded from Cambrian rocks, but which is abundant in Silurian. When we examine the species, the same conclusion is borne out. Of the Actinozoa, the *Favosites* is one which occurs in the Coniston Flags. Of the Crustacea, *Discinocaris* has only been found in the Moffat Shales, and occurring in the mudstones, which have been a subject of much dispute, together with the Graptolites, must be considered along with them. One species of *Acidaspis* seems absolutely identical with a species found in the May-Hill beds of Penlan, Llandovery. The *Harpes* I have not been able to determine with certainty. It is possible there may be two species here. Some specimens much resemble one of the Bohemian species of Étage E; and, indeed, all the fossils form a very similar group to that found in this Bohemian division. *Cheirurus bimucronatus*, although found in the Bala beds, is much more abundant in the Wenlock Limestone. The *Phacopes* have been already alluded to; one much resembles *Phacops Stokesii*, so characteristic of Wenlock rocks. *Encrinurus variolaris* is a fossil confined exclusively to Silurian rocks. The Mollusca do not yield much evidence, being small and badly preserved; the only species I have determined is *Leptæna quinquecostata*, which is exceedingly abundant at Spengill. It is mentioned in Davidson's monograph as ranging from Lower Bala to Upper May-Hill beds. Thus the fossils indicate the Graptolitic Mudstones to have been deposited during the Silurian period. It would be impossible at present to correlate them with their equivalents in Wales; but the beds above them have been identified, by Mr. Aveline, with the Tarannon shales (Geol. Mag. decade ii. vol. iii. p. 376), whilst the basement-bed presents many affinities with the Lower May-Hill beds of Wales. In this case the Graptolitic Mudstones would be either upper May-Hill beds, lower part of the Tarannon shales, or intermediate beds; and the fossils in some degree bear out this view. Of the Graptolites I need not treat, but will consider only the evidence derived from he more highly organized fossils.

c. *Pale Shales.*—These beds have been stated by Profs. Harkness and Nicholson (Quart. Journ. Geol. Soc. vol. xxxiii. p. 478) to present more affinities with the Coniston Flags than with the Graptolitic Mudstones. I see no reason, however, to depart from the view held by the Geological Survey, that they are more closely related to the Graptolitic Mudstones. They are very similar in lithological character, if we omit the Graptolitic beds themselves, which are probably in great part due to the Graptolites.

Of the fossils, *Monograptus lobiferus* occurs well up in the Pale Shales, in a thin mudstone band on Applethwaite Common. More highly organized fossils also occur in the Pale Shales. Profs. Harkness and Nicholson mention some from the high ground between Troutbeck and Skelgill; and I have found here a small brachiopod, apparently a *Meristella.* In the Woodwardian Museum there are two specimens of *Stricklandinia lirata*, Sow., occurring in one block from the Pale Shales of Rebecca Hill, near Ulverston.

On comparing the fossils of the basement-bed and of the Stockdale Shales with those of the Coniston Limestone and Ashgill Shales, we find very few fossils common to the two series. *Favosites fibrosus*, *Leptæna quinquecostata*, *Strophomena siluriana*, and *Cheirurus bimucronatus* are the only species found in both; and of these, *Favosites fibrosus* is a species having an enormous range, whilst *Leptæna quinquecostata* and *Cheirurus bimucronatus* are very rare in the Coniston Limestone, although abundant in the Stockdale series. *Strophomena siluriana*, on the other hand, abounds in the Ashgill Shales, and occurs in one locality, in no great abundance, in the basement-bed.

It appears from the above conclusion that the position of the boundary between the Cambrian and Silurian rocks must be referred to the same horizon, whether we determine it from physical or palæontological evidence. Not only is there a palæontological break between the Ashgill Shales and what has been taken as the basement-bed of the Silurian, but whereas in the Ashgill Shales and underlying beds we get a group of fossils agreeing in all respects with those of the Cambrian series of other districts, in the beds above the Ashgill Shales we find a well-marked Silurian fauna, which will probably be largely added to in future.

5. Coniston Flags.

In the Windermere district an excellent section of these beds is seen in the neighbourhood of the well-known Coldwell and Brathay quarries, situated on the west side of Windermere Lake, about two miles S.W. of Ambleside. They are seen to consist of two well-marked divisions, easily separable by lithological characters. The lower division consists of blue, well-cleaved, and finely laminated flags, of uniform lithological character throughout, and of exceedingly fine texture. This division makes up about a third of the whole thickness of the Coniston Flags. Above these blue flags we find a series of gritty beds, all somewhat similar, but separable into three distinct subdivisions, forming the remainder of the Coniston-flag series. These subdivisions are:—(*a*) a lower series of coarse grey grits, of no great thickness and apparently unfossiliferous; (*b*) a middle series of calcareous, flaggy, fossiliferous grits, of a blue colour and weathering to a rust-brown (this subdivision is about as thick as the subdivision *a*); (*c*) an upper series of gritty flags, of bluish or greyish colour, weathering green, finely laminated, and containing few fossils (this series is of great thickness, forming, indeed, more than half the thickness of the whole of the Coniston-flag series; but nevertheless the lithological characters of the beds fully warrant these divisions, which are borne out by the fossils). For the lower division of the flags I propose to retain the term Brathay Flags of Prof. Sedgwick, as they are excellently exhibited in the Brathay quarry. Moreover, at the time when the term "Brathay Flags" was proposed, it seems to have been applied to these beds, as the relations of the higher beds were somewhat obscure (*cf.* also Cat. Camb. & Sil. Foss. of Woodw. Mus. p. 78).

To the middle subdivision of the higher division the term Coldwell beds was given by Prof. Sedgwick, and this name was used for the same beds by Mr. Aveline (Mem. Geol. Surv. 98 N.E. p. 8); but as this subdivision is evidently connected with the subdivisions above and below it, the term might well be extended to include the three, all well exposed near Coldwell quarry.

The following section (fig. 2) shows, on an approximately true horizontal scale, the relations of these beds.

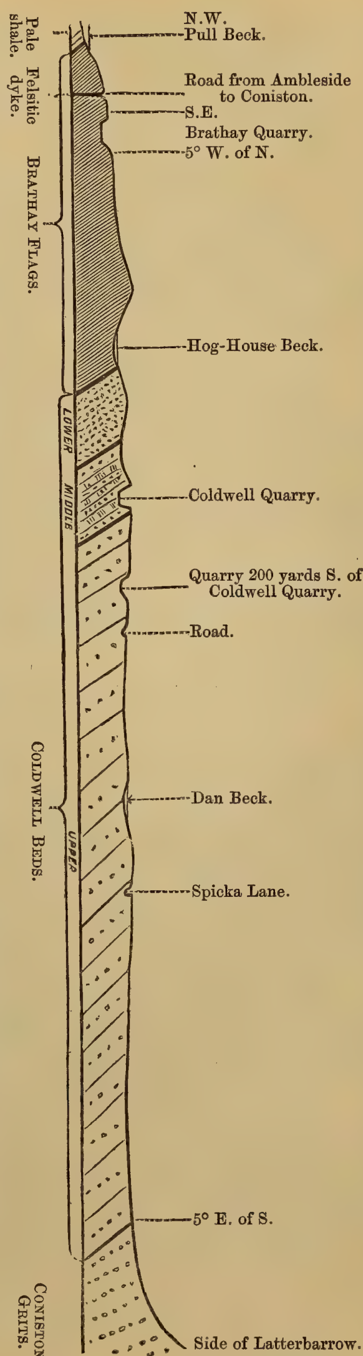


Fig. 2.—*Section from Pull Beck to North Side of Latterbarrow.* (Length of Section about 2 miles.)

The Brathay Flags, as before mentioned, are well exposed in Brathay quarry. The Lower Coldwell Beds form a marked feature across the country, although not exposed in any large quarry. The Middle Coldwell Beds are seen in many quarries, notably Coldwell and Randy Pike; whilst the Upper beds are excellently shown, and fairly fossiliferous, in a quarry about 200 yards south of Coldwell quarry.

The Brathay Flags, when traced across the country, become thicker towards the S.W., whereas when we trace them eastward they become very thin. The Coldwell Beds also alter in the same way, and the lowest subdivision of them dies out between Troutbeck and Kentmere, the other divisions being persistent.

The following is a list of the fossils of these beds in this part of the district:—

Fossils of the Brathay Flags.

Favosites aspera	Stockdale.
Monograptus priodon	Stockdale; Nanny Lane, Troutbeck; Brathay Quarry.
Cyrtograptus	Nanny Lane.
Retiolites Geinitzianus, *Barr.*	Stockdale.
Crinoid	Nanny Lane.
Orthoceras	Stockdale.

All these fossils occur near the base of the Flags; and *G. priodon*, in a very good state of preservation, is very characteristic of this division of the Flags.

Fossils of the Middle Coldwell Beds.

Petraia	West side of Troutbeck.
Crinoids	West side of Troutbeck; Coldwell.
Phacops obtusicaudatus, *Salt.*	Everywhere.
Leptæna	Coldwell.
Orthis	Randy Pike.
Strophomena depressa, *Dalm.*	West side of Troutbeck.
Atrypa?	East side of Troutbeck; Coldwell.
Cardiola interrupta, *Brod.*	West side of Troutbeck.
Pterinea	West side of Troutbeck.
Orthoceras, sp. allied to O. dulce......	Coldwell.
O. laqueatum, *Hall*	West side of Troutbeck; Coldwell; Randy Pike.
O. tenuicinctum, *Portl.*	Troutbeck; Coldwell; Randy Pike.
O. bilineatum	Coniston.
O. subundulatum, *Portl.*	Randy Pike; Coldwell.
O. subannulatum, *Münst.*	Coldwell.

Fossils of Upper Coldwell Beds.

Favosites fibrosa?	Quarry 200 yards south of Coldwell Quarry; Troutbeck.
Favosites (large sp.)	Quarry south of Coldwell.
Monograptus colonus......................	West and east sides of Troutbeck; Quarry south of Coldwell.
Actinocrinus pulcher, *Salt.*	West side of Troutbeck; Quarry south of Coldwell.

Ceratiocaris Murchisoni	West side of Troutbeck; Quarry south of Coldwell.
Peltocaris anatina, *Salt.*	Rebecca Hill; Quarry south of Coldwell.
Phacops obtusicaudatus, var.	Quarry south of Coldwell.
Orthis?	Quarry south of Coldwell.
Acroculia	West side of Troutbeck; Quarry south of Coldwell.
Orthoceras primævum, *Forbes*	East side of Troutbeck; Quarry south of Coldwell.
O. tenuicinctum, *Portl.*	Quarry south of Coldwell.

When we compare the fossils of the Coldwell Beds with those found by Prof. Hughes in the Coniston Grits of Helm Knot, Dent (Mem. Geol. Survey, 98 N.E. p. 11), we see a strong correspondence between the two lists. Moreover *Phacops obtusicaudatus*, which is so very local in the Lake-district proper, being almost confined to a single bedding plane, along which it may be traced for several miles, is also recorded from the beds on the north side of Helm Knot. The lithological resemblance of the Coldwell and Helm-Knot beds is at once apparent on comparison—the lower beds on the north side of Helm Knot, with *Phacops obtusicaudatus* and large *Orthocerata*, being precisely similar to the Middle Coldwell Beds; whilst the beds on the S.W. side of the Knot, with *Graptolites colonus* and *Ceratiocaris*, are, except perhaps in being slightly more gritty, extremely like the Upper Coldwell Beds, having the same fossils, in the Lake-district proper. This correlation will account for the small thickness of Coniston Flags mapped on the east of the river Lune, as compared with the flags of the west side.

The following table shows the relation of the beds in the two districts:—

Windermere District.			Sedbergh District.
Coniston Grits			=Upper Coniston Grits.
Coniston Flags	Coldwell Beds	Upper	=Beds S.W. of Helm Knot, beds of High Hollins, &c.
		Middle	=Beds N. of Helm Knot.
		Lower.	If present at Helm Knot not exposed.
	Brathay Flags		=Coniston Flags (of Frostrow Fell &c.).

The list given by Prof. Hughes from Helm Knot includes only the fossils from the S.W. side of the Knot, which belong exclusively to beds referable to the upper division of the Coldwell Beds. The beds equivalent to the Middle Coldwell Beds in the Windermere district are, as shown in the foregoing paper, found on the north side of Helm Knot, and the following list shows the identity of the fossils:—

Fossils of the Beds on the North Side of Helm Knot.

Phacops obtusicaudatus, *Salt.*
Orthis.
Orthoceras tenuicinctum, *Portl.*
Orthoceras subundulatum, *Münst.*
O. bilineatum.
Cycloceras.

APPENDIX. *On some Species of* PHACOPS.

1. PHACOPS (CHASMOPS) MACROURA, Sjögren.

I would add the following notes to the description given of this Trilobite by Salter, Mon. Brit. Tril. pp. 37, 38.

The tubercles mentioned on p. 38 are not arranged at random, but in roughly linear series, the lines running from before backwards; they are more largely developed behind than in front, and more on the glabella than on the cheeks, being especially marked on the "cat's-ear" lobes. The double row of puncta seems to be characteristic of the species, as I have seen it in at least four specimens in the Woodwardian and Geological-Survey collections.

Body-rings of the axis nearly uniform in breadth and width, being convex. Pleuræ more than twice as wide as the axis, slightly curved downwards at the outer extremity, and ending obtusely. Pleural grooves deep, straight throughout, oblique, running parallel to the sides of the pleuræ at the outer extremity.

The body much resembles that of *P. truncato-caudatus*, Portlock, from which it differs in the uniformity of the body-rings of the axis, the total want of tuberculation, and the much greater curve of the furrows bounding the pleuræ.

Formation. Coniston Limestone.

Localities. Coniston; Applethwaite Common (a beautiful specimen, with the head and seven body-rings preserved, was found there by F. Marr, Esq.); Long Sleddale; Style End (in beds below the felspathic rocks).

2. PHACOPS (ODONTOCHILE) MUCRONATUS, Brongn., var.

I have found numerous specimens of a *Phacops* in the Lake-district corresponding to the description given by Salter (Mon. Brit. Tril. p. 46) of a Trilobite from the slates of Pen-y-rhiw, near Bala. No body-segments have yet been found, but numerous heads and tails. The head is strongly tuberculated; the cheek possesses a spine at the outer corner. The tails are like that figured by Salter, and probably possessed a long spine, of which the cast is preserved in one specimen in my collection, whilst other specimens show indications of its having existed.

The species much resembles *P. obtusicaudatus*, Salt., as regards the head; but the furrows of the glabella are much straighter and shallower, whilst the lobes are nearly equal in width throughout, and all of nearly the same size. The species will probably have to be ultimately separated from *P. mucronatus* and placed under Salter's title, *appendiculatus*.

Formation. Ashgill Shales.

Localities. Ashgill; Skelgill, Nanny Lane, and Applethwaite Common, Troutbeck.

3. PHACOPS (*P.* proper), sp.

A specimen from a bed in the Graptolitic mudstones of Skelgill

Beck, belonging to this subgenus, is deserving of some notice. It much resembles *P. Stokesii*, Milne-Edw., but the glabella is longer as compared with the width, and the axis of the tail is not so flat; the body-segments also of the axis have large tubercles at their extremities. The chief feature, however, consists of a sort of fringe which is seen round one of the cheeks, the margin of the glabella not being preserved sufficiently to show whether it extended all round. It is formed by a single row of round holes.

I believe there is also a smaller species of this subgenus in the same bed, but it is not sufficiently perfectly preserved for identification.

Formation. Graptolitic Mudstones.

Locality. Skelgill Beck. The smaller species is also found at Spengill and Torver Beck.

4. PHACOPS (ODONTOCHILE) OBTUSICAUDATUS, Salter.

This species, which has a general resemblance to *Phacops mucronatus*, var., occurs in the Lake-district proper, almost confined to a single bedding-plane, in the Middle Coldwell Beds, along which it may be traced for many miles. This resemblance is of interest as bearing on evolution; the glabella is of much coarser structure than that of *P. mucronatus*, var., whilst the tail is exceedingly obtuse, that of *P. mucronatus* being very acute and terminated with a long spine. It is very probable that these variations are due to differences of sediment; for whereas we find *P. mucronatus*, var., in extremely fine shales, *P. obtusicaudatus* occurs in coarse grits. In the Upper Coldwell Beds, which are less gritty, I have found a variety of this species in which the side furrows of the tail are slightly bent downwards, and there are some traces of a small spine; in the finer beds of the higher series in Wales we get the more strongly spined *P. caudatus*; whilst in the very fine Wenlock shale the very long-spined *P. longicaudatus* is found.

Formation. Middle Coldwell Beds. (*Note.* The specimen referred to this species from the Ashgill Shales of the Sedbergh district in Prof. Hughes's paper, Geol. Mag. vol. iv. no. 8, is the tail of another species.)

Localities. Many quarries in the neighbourhood of Coldwell; quarries on both sides of Troutbeck; north side of Helm Knot, Dent.

51. *The* Recession *of the* Falls *of* St. Anthony. By N. H. Winchell, Esq., State Geologist of Minnesota. (Read April 3, 1878.)

[Communicated by James Geikie, LL.D., F.R.S.]

In studying the superficial accumulations of the North-west, the phenomena of the drift in the vicinity of the Falls of St. Anthony have come under review, and it has been found that the intimate connexion between the history of that drift and the recession of the Falls has afforded another datum from which to compute the date of the last cold phase of the glacial epoch *. The consideration of this question naturally divides itself into three parts:—

First. The Drift in the vicinity of the Falls of St. Anthony.
Second. The Gorge formed by the recession of the Falls.
Third. The Recession of the Falls.

I. *Drift in the vicinity of the Falls of St. Anthony.*

In describing the Drift in the vicinity of the Falls of St. Anthony it will be necessary to state, in the first place, that the surrounding country presents the same general character as that of most of the North-west. It lies in the midst of that great plain known as the "Mississippi Basin," which extends from the spurs and foot-hills of the Rocky Mountains to the Adirondacks. The surface for hundreds of miles is flat or gently flowing, the slight elevations and depressions being chiefly due to corresponding undulations in the nearly horizontal rocky strata underneath, while the short abrupt hills which give sometimes a rapidly rolling contour are made up of drift deposits. The principal component of the drift is a stony clay, which is the unmodified deposit of the glaciers. Its thickness, outside the river-valley, seems to be about 150 feet. It lies generally in an unbroken sheet, but shows an undulating or rolling upper surface. This accumulation, which is well known under the names of "hardpan" and "boulder-clay" in America, and of "till" in Great Britain, is of two kinds, the differences between which show that it is made up of two distinct deposits; they are

The Grey Hardpan and
The Red Hardpan.

The principal differences between these deposits are these:—*The red underlies the grey* and gradually runs deeper and deeper below an increasing thickness of the latter, towards the west, while

* [Professor Ramsay has noticed a somewhat similar connexion between the history of the drift and the recession of the Falls of Niagara. He thinks the Falls commenced during the deposition of the *Leda*-clay, or a little before the close of the drift period. "If, with accumulated data," he remarks, "the rate of the past recession of the Falls be actually determinable, we shall then be in a condition approximately to show the actual number of years that have elapsed since the close of the North-American drift."—*Quart. Journ. Geol. Soc.* vol. xv. (1859), p. 212.—J. G.]

towards the east it forms the entire thickness of the drift, with the exception of the surface-loam, or *loess*, the grey hardpan being wanting. This is true of the general upland, while in the valley of the Mississippi river the grey hardpan has been distributed further east, reaching as far as St. Paul. The boulders in the lower red hardpan are of many different kinds, but *red quartzite* and *trap of a green colour predominate*; while the upper or grey deposit is distinguished by the presence of fragments of lignite and Cretaceous débris, with large boulders of granite. Moreover the stones in the red hardpan *are generally smaller* than those in the grey.

The lower bed has the bright *red colour of peroxide of iron non-hydrated*, the colour of the upper being earthy, but becoming blue at great depths. The iron in the latter is hydrated, or at least has the usual characters and olive colours of limonitic earths, varying from yellowish to reddish. The red boulder-clay is more gravelly and sandy than the grey. It extends indefinitely eastward, and was probably derived from the ferruginous shales of the Primordial rocks, moved south-westwards by the great continental glacier which preceded the latest glacial epoch. The grey deposit extends indefinitely westward, forming the Leap Hills in Central Minnesota, where it abounds in boulders and gravel, and the Coteau des Prairies in Dakota, where it is sprinkled over with "alkali lakes." It runs under the lacustrine clay of the Red River of the North, and it even there exhibits its strongly alkaline character by yielding alkaline water when penetrated in deep wells. It is derived from the disintegration of the Cretaceous shales and clays, which are charged with sulphates of magnesia and lime and some bitter chlorides; and it often contains large pieces of that formation, even within the limits of Hennepin County, in the state of Minnesota, within which are situated the Falls of St. Anthony. This grey hardpan represents the last cold epoch of the glacial period, and was laid down by ice coming from the north-west and north. In the state of Ohio, and in other places, the difference of colour in the hardpan drift has been attributed to the downward infiltration of the surface-waters to the depth of ten or twenty feet, causing a hydration of the iron and perhaps of other earthy oxides; but in the vicinity of the Falls of St. Anthony this will not explain the difference in colour of the upper and lower deposits. There is very often between these two hardpan deposits a course of red sand, or of red sand and gravel mingled with boulders, evidently the result of a washing of the lower deposit and a stratification of its coarser constituents by running water. Above this course of red gravel and sand lies the grey hardpan, the colour changing immediately from red to grey. It is not at all probable that if infiltrating water changed the colour of the upper deposit, by hydrating the iron, the process would cease so suddenly on reaching the underlying gravel and sand. It would be more likely to have continued through the gravel and sand, and ceased on reaching the impervious red hardpan below. Besides, although the upper portion of the grey hardpan has really been thus changed by infiltration to varying depths, yet its lower portion, where it has its full development, is blue. Another noticeable difference between the red and grey deposits is the presence of a laminated, or often non-laminated, loam, which reaches sometimes fifteen feet in thickness, *over the red hardpan towards the east and south*, especially in the valley of the Mississippi, and its absence over the grey hardpan towards the west, or its occurrence only in very thin and small low patches round its margins. The grey hardpan disappears towards the east gradually, extending further in the valleys than in the uplands; and where the hardpan itself is not seen, sometimes the gravel from it is distributed several miles further, often mingled with a gravel derived from the denudation of the red hardpan. The most easterly portion of the grey hardpan, in the vicinity of the Falls of St. Anthony, not in the valley of the Mississippi, lies within the limits of the city of Minneapolis, on the west side of the river, and there marks the limit of the moving ice which deposited it. This is a remarkable incident of itself. This is the furthest limit to which the ice could move the drift in this neighbourhood. More to the west its force extended much further south, and its boundary seems to mark out roughly the limit of the Big Woods of Minnesota, at least in their southern and eastern portions. The following general section will express the arrangement and natural sequence of the different parts of the drift, when they are all considered, as represented in the vicinity of the Falls of St. Anthony:—

1.	Loam		3 to 6 feet.
2.	2 (*a*).	Grey sand and gravel	0 to 20 feet.
	2 (*b*).	Brick-clay	0 to 25 feet.
	2 (*c*).	Grey sand and gravel with boulders	1 to 20 feet.
	2.	Grey hardpan	0 to 12 feet.
3.	3 (*a*).	Red gravel and sand	0 to 10 feet.
	3 (*b*).	Red fine sand or laminated clay	0 to 10 feet.
	3 (*c*).	Red gravel with stones and boulders	0 to 6 feet.
	3.	Red hardpan	0 to 25 feet.

The foregoing Table summarizes and brings into one view the details derived from a great many separate sections. There are three distinct parts or members of the drift, namely, *loess*, *grey hardpan*, and *red hardpan*; but the separate subdivisions of each member are not all seen at any single point. The subdivisions *a*, *b*, *c* represent modified conditions of the main members or parts, (2 and 3), and are accumulations derived from the washing and redeposition of the finer and coarser constituents of these main members. Nos. 2 (*b*) and 3 (*b*) are very apt to be entirely wanting, No. 2, with perhaps a thin deposit of No. 2 (*a*), being the only representative of the later drift. There are places also where the only representative of the later drift is a heterogeneous mingling of coarse gravel and boulders belonging to No. 2 (*c*). This is more frequently the case near the margin of the later drifts, and beyond it eastward in the valleys. No. 2 (*b*) sometimes rests on the grey hardpan without the intervention of No. 2 (*c*); and in the same manner No. 3 (*b*) sometimes passes into the red hardpan without any intervening bed of gravel and boulders.

In all cases the hardpan is plainly the original deposit, the material from which the other parts have been derived. There is in nearly all cases a greater or less thickness of the red hardpan, the only points at which it is entirely wanting being along the river banks, where it may have been subjected to great erosion and wash, the overlying grey gravel, or grey hardpan, having taken its place. The brick-clay No. 2 (*b*), is extensively used for making bricks, which are usually of a cream-colour; it is laminated, generally horizontally, and contains calcareous concretions and shells of the genus *Unio*. The light colour of the brick is probably due, not to the absence of iron, but to its union with the silica, lime, and magnesia of the clay, forming silicates of those bases. A similarly coloured brick at Milwaukie indicates the presence of the same alkaline bases in the clay, and, *à priori*, points to the existence of the Cretaceous in northern Wisconsin and Michigan as their source, and not to the presence of the sea during the deposit of the drift. This clay contains sticks and leaves. It is sometimes in strata that undulate over wide intervals, rising five or six feet in twelve or fourteen rods. It lies on a fine sand, with which its strata are not conformable, the transition from the sand to the clay being abrupt. It also sometimes rests on a layer of coarse gravel and sand with boulders. The latter is the case at St. Paul within the valley of the river. This clay prevails in the old valley of the Mississippi river above the Falls of St. Anthony, and especially in the valley of Bassett's Creek at Minneapolis.

II. *Gorge formed by the recession of the Falls of St. Anthony.*

The gorge formed by the recession of the Falls extends, with pretty nearly the same width and outward characters, to Fort Snelling, a distance of about eight miles, where the river enters a gorge of a very different kind. This is an older river-valley, one which probably witnessed, at some more remote period, the recession of the Falls of St. Anthony past the site of the Fort, up the Minnesota valley towards Shakopee. Gen. G. K. Warren was the first to call attention to the remarkable character of the Minnesota valley and its great size—so disproportionate to the comparatively small quantity of water which now descends it*.

The Minnesota occupies the main valley, the external character of which resembles that of the Mississippi valley below Fort Snelling, the Mississippi river above the union of the two rivers being merely a subordinate tributary. The Minnesota, it is true, is smaller at the present time than the Mississippi; but it shows evidence of greater age, and of having flowed in larger volume during some late period of its history. The principal points of

* 'Report of the Chief of Engineers for 1875.'

difference between the Mississippi valley above Fort Snelling and the greater valley which it enters at that place are as follows :— The gorge above the fort is about a quarter of a mile wide ; below the fort it is a mile wide, the same width continuing up the Minnesota above the fort. The walls of the gorge above the fort have the appearance of having been freshly broken, the rock lying in uncovered fragments in a talus at their base ; the older valley, on the other hand, is flanked by bluffs that are rounded off, the fragments being hidden by a loam, or even by drift gravel, so that they are turfed over or even wooded from the water to the top. The limestone in the bluffs above the fort is visible without interruption from the fort to the Falls ; in the older valley below the fort it is only interruptedly exposed, and is cut out and broken down by other small tributary streams, especially at St. Paul (such valleys now being filled with drift), and above the fort the outcrop of the Trenton is soon lost sight of under a thick covering of drift.

There is a perpendicular section of the drift running along the top of the limestone in the Mississippi valley, above the fort, as if the drift had fallen when the rock that supported it gave way. This drift section abuts immediately upon the river, and forms a part of the high bluffs that enclose it ; in the old valley which the Mississippi joins, the drift has been deposited *within the rock bluffs* and hides them, and there is no natural perpendicular section of drift materials running along the tops of the bluffs. The direction of the Mississippi above the fort is towards the south-east ; but after entering the old valley it turns at a right angle and runs north-eastwards, that being also the direction of the Minnesota above the fort.

Near Fort Snelling, but below the union of the two rivers, lies a low, long, alluvial island (Pike Island), which points to the former rapid accumulation of débris at that point in the river-gorge. It is just opposite the point of débouchure of the Mississippi into the old valley, and must have been formed since the excavation of the gorge. On the opposite side of the old valley, from the point of entrance of the Mississippi, the rock-bluff also presents the exceptional character of being freshly broken down by rapid undermining erosion by the river. It seems as if, at some time later than the covering of the bluffs by the loam, the current had been driven violently and unusually against that bluff, since, both above and below, the bluffs are not thus freshly cut.

There is one other point in connexion with the description of this gorge to which it is necessary to direct attention. The foregoing facts are alone sufficient to suggest to the reflective observer some difference in the age of these two portions of the great valley. When, however, it is found that above the Falls of St. Anthony, but within the corporate limits of Minneapolis, the rock-bluffs which so closely confine the river below the falls within the width of a quarter of a mile are suddenly diverted from the river, running inland about a mile apart, covered with loam and even with drift like the bluffs below the fort, it becomes evident that here the

Mississippi is running in an ancient channel, and that for some reason the course of that great river has been changed, the narrow gorge that extends between Bassett's Creek and Fort Snelling being of course the new cut.

On tracing out the range of the rock-bluff on the west side of the Mississippi above the falls, hidden as that bluff is by loam and drift, it is found to fall rapidly away from the river near the railroad bridge, turning south-westwards across the city, ascending the south side of Bassett's Creek, which joins the river some distance further up, and finally passing out of sight in a south-westerly direction under a thick accumulation of drift.

Going now across Bassett's Creek, and tracking the outcrop of the limestone, we pass over a wide valley filled with alluvium or brick-clay—much too large a valley to have been formed by the sluggish creek that now flows through it. We find that the limestone which, along the river, has a trend a little west of south, on reaching the valley of the creek swings more westwardly, parallel with the outcrop of the rock on the south side of the creek, and thus encloses a valley, even a gorge, cut in the limestone and sandstone, much wider than the gorge now being cut by the recession of the Falls, but in width corresponding with that between the rock-bluffs above the mouth of Bassett's Creek, and comparable to that below Fort Snelling.

Here, then, we have an old drift-filled valley, evidently formed at some more remote period than the present, which once held the Mississippi as it ran between rock-bound bluffs towards the Minnesota and reached that great valley at some point between Fort Snelling and Shakopee. Bassett's Creek, in making its way to the Mississippi, falls into the depression caused by the old valley in question, and follows it till it reaches the present river-channel. This ancient drift-filled valley is over one hundred feet deep. This has been ascertained by the borings made for deep walls, and the materials that fill it up are found to be hardpan and fine alluvial clay, from below which rises artesian water.

Such ancient buried river-channels are not uncommon. A number have been described in various parts of the United States*. It is not common, however, that circumstances have so combined as to produce, by the change of course of a river and the burial of its old valley, a retreating waterfall, which, by its uniform rate of recession, fixes the date of such change. Niagara river has thus been changed; but its rate of recession has not been uniform, owing to changes in the nature of the rock undergoing the process of erosion, and to a dip in all the formations towards the south, which, of course, gradually diminishes the height of the fall. There seems also to be no recognized datum-point by which to establish a rate of recession. That the Falls of Niagara have receded from Queenston Heights has been sufficiently demonstrated by Lyell; but the rate assumed, based on observations of no very accurate kind, and

* Compare 'The Geology of Ohio,' vol. ii. p. 12 *et seq.*

only extending through an interval of forty years, requires a period of time between eleven and twelve thousand years*.

III. *The Recession of the Falls of St. Anthony.*

Fortunately the recession of the Falls of St. Anthony must have been very uniform. The rocks are horizontal and of unvarying composition. A white friable sandstone, over one hundred feet thick, called the St.-Peter sandstone, underlies a more enduring limestone, known as the Lower Trenton limestone. It is this conjunction of formations of different durability, the harder overlying the softer, that gives origin to the Falls. The Lower Trenton is about thirty feet thick, and includes some layers of green shale.

It is not possible to calculate the time required for the recession of the Falls from Fort Snelling by relying on the known recession since the settlement of the region, though they have gone back about five hundred feet. This extraordinary rate has been caused by artificial means, chiefly by the construction of saw-mills and dams, diverting thereby the current or concentrating it on certain points, and by the passage of logs over the Falls. We must have recourse to historical data. Fortunately we have records of the appearance of the Falls at different times, by which we can fix their position. They were discovered by Father Louis Hennepin, who saw them first in July 1680, in returning from his captivity among the Dakotas. He gives the following brief description, as translated from the French of the Amsterdam edition of his works (1704, chap. 44, p. 319):—"In ascending this river ten or twelve leagues, navigation is interrupted by a fall, which we named in honour of St. Anthony of Padua, whom we had chosen as patron of our enterprises. This fall is fifty or sixty feet in height, and has an island of rock in the form of a pyramid in the middle of the *chute*." The 'Historical Collections of Louisiana,' part iv., contain a translation of Hennepin's narration, in which he gives "40 or 50" feet as the height of the Fall.

Jonathan Carver, a captain of provincial troops in the employ of Great Britain, a native of Connecticut, visited the Falls of St. Anthony during his extensive travels in the North-west in 1766. In the London edition of his Journal, 1778, p. 69, Carver thus describes them:—"This amazing body of waters, which are above 250 yards over, form a most pleasing cataract; they fall perpendicularly about 30 feet, and the rapids below, in the space of 300 yards more, render the descent considerably greater. . . . . . In the middle of the Falls stands a small island, about 40 feet broad and somewhat longer, on which grew a few ragged hemlock and spruce trees; and about halfway between this island and the eastern shore is a rock lying at the very edge of the fall in an oblique position, that appeared to be about 4 or 6 feet broad, and 30 or 40 long. . . .

* 'Travels in North America.' Lyell, it is true, does not adopt that datum, but arbitrarily divides it by three, getting 35,000 years for the time needed for the above recession.

. . . At a little distance below the Falls stands a small island of about an acre and a half, on which grow a great number of oak trees, every branch of which, able to support the weight, was full of eagles' nests." The engraving accompanying this description is that seen in 'Winterbottom's America,' and is reproduced in 'Harper's New Monthly Magazine' for October 1875, and wrongly attributed to Father Hennepin. Carver's original engraving shows an island above the Falls, which is omitted in the copy in the Magazine. Carver states on the engraving that the breadth of the Falls was about 600 feet. This engraving also shows an insignificant island just in the brink of the Falls, extending neither above nor below the Falls, and an apparently detached block of limestone lodged on the brink between it and the eastern (or northern) shore. In the stream below the Falls is represented a larger low island, not rocky, but alluvial, nearly circular, and covered with timber.

Lieut. Pike visited the Falls, in the service of the United States Government, in September 1805. His Journal, published in London in 1811, is entitled 'Exploratory Travels through the Western Territories of North America in 1805–6–7.' He says of the Falls:—"The Falls of St. Anthony did not strike me with that majestic appearance which I had been taught to expect from the descriptions of other travellers. On an actual survey, I find the portage to be 260 poles; but when the river is not very low, boats ascending may put in 31 poles below, at a large cedar tree, which would reduce it to 229 poles. The hill on which the portage is made is 69 feet ascent, with an elevation at the point of debarkation of 45°. The fall of the water between the points of debarkation and of re-landing is 58 feet; the perpendicular fall of the chute is 16½ feet: the width of the river above the chute is 627 yards, below 209. In high water the appearance is much more sublime, as the great quantity of water then forms a spray which in clear weather reflects from some positions the colours of the rainbow, and when the sky is overcast covers the Falls in gloom and chaotic majesty."

Major Stephen H. Long visited the Falls of St. Anthony in a six-oared boat in 1817. The following is his account of the Falls:—"The perpendicular face of the water at the cataract, as stated by Pike in his Journal, is sixteen and a half feet, which I found to be true by actual measurement. To this height, however, four or five feet may be added for the rapid descent which immediately succeeds the perpendicular fall within a few yards below. Immediately at the cataract the river is divided into two parts by an island, which extends considerably above and below the cataract, and is about 500 yards long. The channel on the right side of the island is about three times the width of that on the left. The quantity of water passing through them is not, however, in the same proportion, as about one third part of the whole passes through the left channel. In the broadest channel, just below the cataract, is a small island also, about fifty yards in length and thirty in breadth; both of these islands contain the same kind of rocky formation as the banks of the river, and are nearly as high. Besides these there are immediately at the foot of the cataract two islands of very inconsiderable size, situated in the right channel also. The rapids commence several hundred yards above the cataract, and continue about eight miles below. The fall of the water, beginning at the head of the rapids, and extending two hundred and sixty rods down the river to where the portage-road commences, below the cataract, is, according to Pike, fifty-eight feet. If this estimate be correct, the whole fall from the head to the foot of the rapids is not probably much less than one hundred feet"*.

In 1823 Major S. H. Long again visited the Falls of St. Anthony on his way up the Minnesota river and to Lake "Winnepeek," under orders of the Secretary of War. Prof. Keating, of the University of Pennsylvania, who accompanied him as geologist and naturalist, thus describes the Falls:—"An island, stretched in the river both above and below the fall, separates it into two unequal parts, the eastern being two hundred and thirty yards wide, and the western three hundred and ten. The island itself is about one hundred yards wide. From the nature of the rock, which breaks into angular and apparently rhomboidal fragments of a large size, this fall is subdivided into small cascades, which adhere to each other so as to form a sheet of water unrent, but composed of an alternation of retiring and salient angles, and presenting a great variety of shapes and shades; each of these forms in itself a perfect cascade, but when taken together in one comprehensive view they assume a beauty of which we could have scarcely deemed them susceptible. . . . . . Concerning the height of the fall and breadth of the river at this place, much incorrect information has been published. Hennepin, who was the first European who visited it, states it to be fifty or sixty feet high. It was this traveller that gave it the name which it now bears, in honour of St. Anthony of Padua, whom he had taken for the protector of his discovery. He says of it that 'it indeed of itself is terrible, and hath something very astonishing.' This height is by Carver reduced to about thirty feet; his strictures upon Hennepin, whom he taxes with exaggeration, might with great propriety be retorted upon himself; and we feel strongly inclined to say of him, as he said of his predecessor, 'The good father, I fear, too often had no other foundation for his accounts than report, or at least a slight inspection.' Pike, who is more correct than any traveller whose footsteps we have followed, states the perpendicular fall at 16½ feet: Major Long measured it in 1817 with a plumb-line from the table-rock from which the water was falling, and found it to be the same. Mr. Calhoun measured it while we were there with a rough water-level, and made it about fifteen feet. The difference of a foot is trifling, and depends on the place where the measurement was made . . . . . . Below the fall the river contracts to about two hundred yards. There is a considerable rapid both above and below; a portage of two hundred and sixty poles in length is usually made here: the whole fall, or differ-

* 'Collections of the Minnesota Historical Society'

ence of level between the place of disembarking and that of reloading, is stated by Pike to be fifty-eight feet, which is probably very near the truth; the whole fall to the foot of the rapids, which extend several miles down the river, may be estimated as not far short of one hundred feet."

In 1835 the Falls were visited by G. W. Featherstonhaugh, an Englishman commissioned as "United States Geologist;" and his account of them is given in a 'Report of a Geological Reconnaissance made in 1835 from the seat of Government to the Coteau des Prairies.' "An island about 450 yards long divides the Mississippi into two parts at the Falls of St. Anthony, which have a very irregular outline, owing to the soft sandstone being washed out unequally in places, and the superincumbent strata of limestone falling down in large blocks; these are piled up in large quantities on the bed of the river immediately at the foot of the Falls.

"That part of the river on the north side of the island is about two hundred and twenty yards in width. There is a very smooth section of the rocks here to the water, about 90 feet. I should think the fall would not average more than twenty feet. . . . . On the south side of the river the line of the Falls is a very irregular curvature, and measures about 450 yards to the island. The height of the fall does not appear so great on this side, owing perhaps to the bed of the river being so much choked up with the fallen slabs. It is a wild rocky scene, but deficient in interest as a waterfall on account of its want of height."

In addition to these, we have the account of Beltrami, written in 1823; but his description does not give much information useful in this connexion.

The above statements may be summarized, and the following data arrived at:—

Hennepin, 1680.—Pyramidal rocky island dividing the fall near the middle. Height of the fall, 50 or 60 feet (or "40 or 50 feet").

Carver, 1766.—Width of river 250 yards (or "about 600 feet"); height of the fall 30 feet; a small island in the middle of the fall 40 feet broad, and "somewhat longer," with hemlock and spruce trees, and another of an acre and a half a little below the Falls, with great quantities of eagles' nests; an island also above the Falls; an oblique rock in the brink of the Falls, halfway between the island and the east shore, "about five or six feet broad, and thirty or forty long."

Pike in 1805.—The waterfall 16½ feet; width of the river above the Falls 627 yards, below 209; portage 260 poles.

Long in 1817.—An island, five hundred yards long, separated the cataract into two parts, extending also above and below the Falls; the fall on the west side three times as wide as that on the east; but one third part of the water descends the east channel. A small island, 50 yards by 30, just below the cataract in the west channel. These islands are rocky, with the same formation as in the banks, "and nearly as high;" two others, of fallen fragments and of small size, near the foot of the cataract in the west channel.

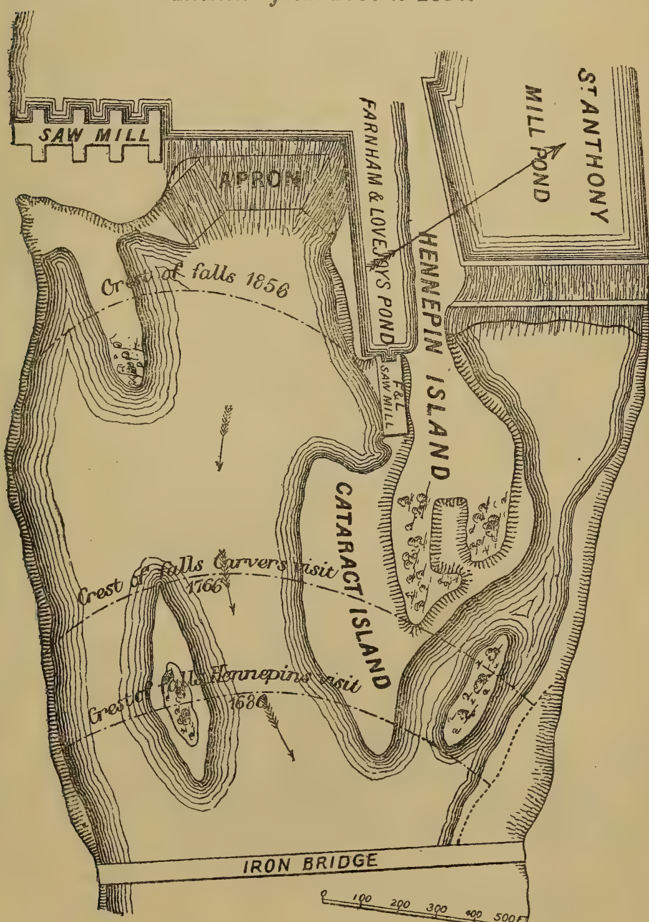
Beltrami in 1823.—Only distinctly mentions an island in the Falls, and an island of sandstone below, with maples.

Keating in 1823.—An island in the river both above and below the cataract, separating it into two unequal parts, the eastern 230 yards, and the western 310 yards wide, the island itself being 100 yards wide; below the Fall the river contracts to about 200 yards.

Featherstonhaugh in 1835.—The average fall is not far from 20 feet; an island, 450 yards long, divides the fall unequally; the channel on the east of the island 220 yards wide, that on the west 450.

By combining and adjusting these statements with each other, a continued record is found of the appearance of the Falls since their discovery, and by the present existence of islands in the channel and in the cataract the position of the Falls at certain dates may be satisfactorily established. When they were discovered by Hennepin they were divided by Spirit Island, and were much higher than now, owing probably to the contraction of the gorge below the falls, as mentioned by Keating in 1823. The gorge across Spirit Island has a width of 1350 feet, determined by a system of triangulation by Prof. Rhame, of the University of Minnesota; while the width of the gorge, including Hennepin Island, is 1700 feet at the point where the Falls were in 1856. Below Spirit Island the gorge becomes still narrower. When Carver saw the Falls in 1766 they were just leaving Spirit Island and entering on Hennepin Island. The many inaccuracies in Carver's description, and in his illustration, render it almost certain that he wrote his account and drew his sketch at some time subsequent to his visit. His use of the past tense in the expressions, "on which *grew* a few ragged hemlock and spruce trees," "that *appeared to be* about five or six feet broad," and "*was* full of eagles' nests," seems to confirm this supposition. The island which Carver's engraving shows above the Falls must be intended for Hennepin's Island, as he remembered it, which now divides the Falls; but it is very much out of the right position even to represent any island; while the "oblique rock" which he noted in the brink of the east fall was the extremity of the submerged toe of the same island. The rocky substructure of an island would extend in all directions beyond the actual visible island, and would appear, at the proper time, as an isolated projecting rock as the earthy covering gave it more and more protection by dividing the current. At that time the water of the river completely surrounded the visible portion of Hennepin Island, *above the brink of the Falls*, as Carver naturally represents. The projecting rock was "oblique," because the limestone rock falls off in rhomboidal masses, governed by the preexisting jointage-planes, thus causing a zigzag outline even across the whole brink, as later fully described by Keating. Carver's estimates of distance are very inaccurate. He mentions "about 600 feet" as the width of the Falls when he saw them; but they must have been 1400 feet, as determined by careful measurement. The small island which Carver's engraving shows in the brink of the Falls, somewhat to the left of the middle, was the upper end of Spirit Island, while the low island below the Falls, which he represents as nearly circular and covered with trees containing great numbers of eagles' nests, can be no other than the lower end of the same island. If his engraving is correct in showing two islands here, it can only be accounted for by supposing that the narrow strip of limestone which constitutes the top of the island had fallen down in the intervening space, and the sandstone had been washed away by the river, thus causing two parts, or two islands, where at first there was but one. This would necessitate the placing of Carver's line of the crest of the Falls some distance

Plan of the Mississippi River at St. Anthony's Falls, showing Recession from 1680 *to* 1856.



further up the channel than is represented by the accompanying diagram (p. 897) of the river at this place, that part of the island which, in that case, he saw in the brink of the falls having entirely disappeared. But it is not necessary to suppose any such thing if the general inaccuracy of his description be borne in mind. His engraving is the copy of his pencil sketch, made probably from memory after he had left the place; and the representation of an island as *low* which ought to have been *high* and *rocky*, rendered it somewhat necessary to avoid the hiding of the falls in the west channel, and when engraved in London would be no unexpected error, and would hardly be regarded as an imperfection by the general reader. Hence he so reduced the height of the lower portion of the island as to make it appear like another island; the engraver then perpetuated the appearance, not knowing the facts. It is possible also that he *actually sketched it as two islands.* His attention had been directed during his stay to the *island with the eagles' nests* *, about which he speculates at some length in his Journal, and to the *island dividing the Falls.* When he came to make his sketch, he expressed both prominent ideas without regard to the exact manner in which they were topographically united or related. Whichever hypothesis may be correct, it is not possible for the island he places in the brink of the Falls to have been Hennepin Island. Besides the general agreement of the whole account with the accounts of subsequent travellers, on the supposition of its having been Spirit Island, and the statement that it was *in the middle of the Falls,* Carver's engraving shows two men in the act of portage of a canoe *along the east shore,* below the Falls—showing that the view was intended to represent the *principal fall* (if not the whole), while the channel on the east of Hennepin Island is now, and always has been since it began, about one third the size of that on the west side. Thus Carver's description, aided by his very imperfect illustration, fixes the position of the Falls in 1766 at the very foot of Hennepin Island.

Lieut. Pike makes no mention of any island in the Falls in 1805, though he gives a description of the Falls themselves. When he arrived Spirit Island must have been wholly below the Falls, and Hennepin Island must have come further into them, as described by Major Long in 1817. That island then divided them unequally, the main channel being on the west side of the island. This is the first distinct mention made of Hennepin Island, although Carver must have intended to represent it in his engraving. It will also be seen, by Major Long's description, that Carver incorrectly represented as low and alluvial an island which was really high and rocky. Spirit Island *still exists,* and is rocky, rising nearly as high as the banks on either side of the river. It must have been there when Carver saw the Falls. In 1823 Keating and Beltrami saw the Falls in pretty much the same position as Long in 1817; and Featherstonhaugh again, in 1835, repeats the same general description.

* Spirit Island was still the abode of eagles in 1856, when the country was first permanently occupied.

It is tolerably well known where the Falls were, in the west channel, in 1856. The Falls in the east channel have not receded perceptibly since that date, while those in the west channel have gone back about 500 feet, as already stated. In general terms they were then abreast of Farnham and Lovejoy's saw-mill, which stands on the west side of Hennepin Island. They had a horseshoe shape, bending considerably upward in the centre, and sweeping downward along either shore, their ends being nearly opposite. If the statements of the earliest settlers are correct, the line of the crest in the west channel met the island about 100 feet below the lowest portion of the flat undisturbed portion of limestone rock on which Farnham and Lovejoy's mill-dam is erected, the mill itself having been originally erected in a little notch or jog in the Falls, partly on the limestone and partly below the Falls, close on the shore of the island.

The most careful measurement ever made of the river between Fort Snelling and the Falls of St. Anthony was conducted by Gen. G. K. Warren. His maps have never been published; but, through the courtesy of Gen. A. A. Humphreys, a tracing of that covering this interval has been obtained, which makes the distance almost exactly eight miles. Prof. Rhame has made a series of triangulations with the view of ascertaining as nearly as possible the amounts of recession since Hennepin's and Carver's visits, and the diagram (p. 897), drawn to scale, is based on his measurements. It is evident that the interval between Carver's time and 1856 is the most reliable datum, the statements of Hennepin not enabling us to determine *at what point* in Spirit Island he saw the crest of the Falls. Still, for the purpose of comparison, a point has been assumed on Spirit Island, and from it measurements have been made. It is presumed that Hennepin saw the Falls when they were near the middle of Spirit Island, at a point, in the undisturbed limestone rock of the island, in a large reentrant angle which runs from the top of the limestone to the bottom on the east side, and 415 feet above the line of the upper end of the stone piers supporting the lower or iron bridge. That makes the recession between the discovery of the Falls and Carver's visit 300 feet; between Carver and 1856, 606 feet; and the whole recession since Hennepin in 1680, 906 feet. This gives us three rates of recession, viz. :—

(1) Between Hennepin and Carver	3·49 feet per year.
(2) Between Carver and 1856	6·73 „
(3) Between Hennepin and 1856	5·15 „

The times required for recession from Fort Snelling would be respectively :—(1), 12103 years; (2), 6276 years; and (3), 8202 years. The average of these is 8859 years; but owing to the exactness of the datum between Carver and 1856, it is likely that the actual time involved would be more nearly expressed by taking that only into the calculation.

Now this, it is true, only expresses the time involved in the

3 O 2

recession from Fort Snelling, which is several miles above St. Paul. There must have been a prior time when the Falls were at St. Paul, and even below that point, inasmuch as the same conjunction of circumstances and the same formations extend several miles below that city. It is not probable, however, that any data will ever be discovered for computing that period of recession; it must have been during preglacial or interglacial time, and nearly all the traces of that history have been obliterated by the ice of the last cold epoch of the glacial period. That recession must have continued past Fort Snelling, along the old valley, and towards Shakopee, when the Falls must have been reduced to nothing by the passage of the river over other formations; or they must have turned more northwardly, caused, in that case, by the waters of the Mississippi only. They may have continued their recession, and probably did, through the intervening portion of Hennepin county, to the present wide valley occupied by Bassett's Creek, and into the present Mississippi valley above its mouth, to near the mouth of Shingle Creek, where, owing to the "running out" of the Trenton and the lack of artificial preventive measures, the preglacial Falls of St. Anthony suffered a "going out," like that anticipated a few years ago at their present site.

Now it may not be plain how this bit of geological history, so measured off, expresses the date of the last cold epoch of the glacial period. It is by the following steps:—

1. The reality of the glacial period, as announced by Prof. L. Agassiz, with slight modifications, is taken as demonstrated by the concurrent observations and opinions of the geologists of Europe and America.

2. The truth of the astronomical theory of the recurrence of cold periods in the climate of the earth, as advocated by Dr. James Croll, is also admitted.

3. Hence the succession of glacial and interglacial epochs, as demonstrated also by the study of the drift deposits themselves, of varying lengths and intensity, must be admitted.

4. The latest glacial drift, in the vicinity of the Falls of St. Anthony, does not extend, in much force, to the south and east of Minneapolis; but in those directions a very different kind of drift is found to prevail.

5. Hence the choking up of the preglacial river-gorge, along the west side of the present channel, must have been accomplished near the acme of glacial cold, or at least when the *effect* of that cold on the superficial materials was greatest.

6. The river thus crowded out of its old valley made for itself a new channel further east, and at the point where it reentered its abandoned gorge it gave origin to the postglacial Falls of St. Anthony by plunging over the limestone in which the old gorge had been excavated.

7. Hence the gorge from Fort Snelling to the mouth of Bassett's Creek is postglacial, above Bassett's Creek and below Fort Snelling preglacial or interglacial.

Discussion.

The President remarked that the result arrived at by the author gave a period not very dissimilar to that which was determined by Sir Charles Lyell in the case of the Falls of Niagara.

Prof. W. Boyd Dawkins said that the calculation was based on the assumption that the rainfall had been constant in the district, and that the quantity of water descending over the Falls had been constant. This assumption he regarded as, in all cases, quite unwarranted, considering the changes that we know to have taken place in Europe in consequence of the destruction of forests &c. He noticed the great changes of climate that have taken place in America owing to the same cause. Hence he regarded all attempts to establish a chronology for geological periods by means of such facts as the recession of waterfalls as based on a fallacy. It seemed to him to be the duty of geologists to point out the impossibility of correlating historical and geological time.

Prof. Hughes thought that there were too many important sources of error in the data to allow us to attach any value to the results: 1st, it was doubtful whether the exact amount of former extension of the rock could be estimated from such observations as those recorded by the earlier travellers; 2ndly, the period down to which glacial conditions prevailed did not appear, from what he had heard of the paper, to be very clearly made out; and, 3rdly, if these points could be proved, they would involve such changes, from the climatal conditions that would allow the interception of the streams of neighbouring valleys by glacier-ice, to the present state of things, when the existence of saw-mills implied ancient forests being destroyed, that uniformity in the rate of waste certainly could not be assumed.

52. *On the* Section *of* Messrs. Meux & Co.'s Artesian Well *in the* Tottenham-Court Road, *with* Notices *of the* Well *at* Crossness, *and of another at* Shoreham, Kent; *and on the probable* Range *of the* Lower Greensand *and* Palæozoic Rocks *under* London. By Professor J. Prestwich, M.A., F.R.S., F.G.S., &c.

In 1851* I expressed an opinion that, as the Upper and Lower Greensands, with the intermediate Gault, cropped out from beneath the Chalk both on the north and south of London, the same strata, in all probability, passed beneath the chalk-basin without break, and that the *Lower Greensand* might be found available as an additional source of water supply to London. The boring made shortly afterwards at Kentish Town† by MM. Degousée and Laurent, of Paris, showed, on the contrary, that while the Upper Greensand and the Gault were prolonged as expected, the Lower Greensand was absent, and was replaced, at a depth of 1114 feet, by strata of *hard micaceous red and variegated fine-grained sandstones and clays.* These were traversed for a thickness of 188 feet, when the work was abandoned.

In the absence of fossils, and the confusion produced by the introduction from above of débris and extraneous fossils from the Gault and Upper Greensand, much uncertainty prevailed for a time with regard to the age of these sandstones, which were considered by some as modified forms of the Lower Greensand or the Wealden, and were referred by others to Permian or Triassic strata. From a subsequent examination of the *Old Red Sandstone* in the neighbourhood of Frome, I came to the conclusion that they belonged to strata of that age‡, as I found the Kentish-Town specimens agreed closely with the Mendip beds in lithological characters, whereas there was, on the whole, a want of agreement with the Permian or Triassic series. I was confirmed in this view after seeing the Red Sandstones and Marls, belonging to the Devonian series, which crop out from beneath the Coal-measures in the neighbourhood of Mons in Belgium.

Still, owing to the absence of fossils, an uncertainty existed on the subject, which has now been effectually removed by the recent boring at Messrs. Meux & Co.'s brewery. This well-known brewery is situated at the south end of the Tottenham Court Road, at its junction with Oxford Street. The original well was sunk many years ago, and carried into the Chalk to a depth of 365 feet. In

* See 'The Water-bearing Strata around London,' by the author. Van Voorst, 1851.

† Quart. Journ. Geol. Soc. vol. xii. p. 6, 1856.

‡ Report of Royal Coal Commission of 1869, vol. i. p. 161; Anniversary Address to the Geological Society for 1872; and Min. of Proc. Civil Engineers, vol. xxxvii. p. 14 (1874).

the hope of obtaining a better supply of water from the Lower Greensand, Messrs. Meux & Co. resolved to carry a boring down through the remainder of the Chalk and the Gault, in the hope of reaching the former formation.

The level of the surface at the brewery is 85 feet 7 inches above Ordnance datum, that of the Kentish-Town well being 186 feet 6 inches. A new bore-hole, of the large diameter of 13 inches, was commenced. At 840 feet the bore-hole was reduced to a diameter of 9 inches, and from 902 feet for the remainder of the depth to 7 inches. The clean, regular cores, often many feet in length, of the several formations passed through brought up by the diamond-boring process are very remarkable.

The Chalk was found to have a total thickness of $652\frac{1}{2}$ feet, while at Kentish Town it is 645 feet thick; the Upper Greensand 28 feet, and at Kentish Town $13\frac{3}{4}$ feet*; the Gault 160 feet, and at Kentish Town $130\frac{1}{2}$ feet. Here the similarity ends. At the base of the Gault, a seam from 3 to 4 feet thick of phosphatic nodules and quartzite pebbles was met with. Under this, the bore-hole entered a sandy calcareous stratum of a light ash-colour, which passed into a compact light-coloured or white limestone, and then into a rock having the appearance of an oolite, being composed of fine calcareous grit in a calcareous paste. Some portions of these strata were more sandy than others, and a small quantity of mica and a few grains of chlorite were occasionally to be detected. This rock was in the place of the *Lower Greensand*, but it bore no resemblance to our ordinary Lower Greensand. Fortunately, some of the beds contained plentiful casts and impressions of shells, which were recognized by Mr. Etheridge, of the Geological Survey, as Lower Greensand fossils. Possibly these beds may represent the middle division or the Ragstone.

The commoner forms were small species of *Cardium* and *Cerithium*, together with a *Trigonia* and an *Exogyra*, some corals and many Foraminifera; the only specific determinations, however, yet made are:—*Cardium Hillanum*, *Trigonia alæformis*, and *Trochocyathus Harveyanus*. These, however, with the general facies of the fossils, satisfied Mr. Etheridge that these beds are the representatives of the Lower Greensands of Kent.

The hopes that were hereupon raised, that, the Lower Greensand being reached, the ordinary loose sands which form so large a part of that formation in Kent and Buckinghamshire might be met with, and a supply of water obtained, were not, however, destined to be realized.

After passing through 64 feet of these calcareous strata, the lower portion of which became grey and argillaceous, the bore-hole suddenly entered, at a depth of 1064 feet, into mottled red, purple, and greenish shales, occasionally finely micaceous, in parts very calcareous,

* I have adopted Mr. Whitaker's reading (Mem. Geol. Survey, vol. iv. p. 498) for the thickness of this bed, in preference to the one originally given by myself; but still there is an uncertainty on this point.

and with a dip of 35°*. These, with lenticular seams or thin beds of hard grey and red sandstone or quartzite, and with beds of red marl, continued through a depth of 80 feet, when all doubt being removed as to the geological age of the strata, the work was stopped.

A good many fossils were met with from time to time in the shales, among which Mr. Etheridge recognized the following:—

Spirifer disjuncta.	Orthis.
Rhynchonella cuboides.	Chonetes.
Edmondia.	

The first two are Upper Devonian species, while the *Edmondia* is a characteristic Devonian genus †.

Further, in lithological characters, the rock-specimens obtained from this boring agree perfectly with those I had an opportunity of seeing, in company with Mr. Warington Smyth and Dr. J. Evans, last year in the neighbourhood of Pernes, near Bethune, where the Upper Devonian strata crop out from beneath the Chalk, with a dip 28° S.W., and are in close relation with the adjacent Coal-measures at Marles and Auchy-au-Bois‡.

For particulars of the section, which I have given at the end of this paper (p. 912), I am indebted to Major Beaumont, the Managing Director of the Diamond-boring Company, and to Mr. Etheridge, aided by specimens in my own possession and in the Oxford University Museum, which has been liberally furnished with a very fine series of cores by Messrs. Meux & Co.

Thus the great problem of the existence of Palæozoic rocks at an accessible depth under London, and of the absence of the Jurassic series, as suggested upon sound theoretical grounds by Mr. Godwin-Austen, has been solved in the affirmative. This geologically important work further shows that while the range of the Lower Greensand is interrupted by the underground Palæozoic ridge, the limits of that interruption do not extend at this point south of a line passing through the centre of London.

The value of the *first* determination consists in the fact that in the range of the Carboniferous series through Belgium and the north of France they are everywhere accompanied, on the same strike, by Devonian strata, and the latter strata are constantly brought by great faults and flexures into juxtaposition with the Coal-measures.

* The cores gave so perfect a vertical section that the angle of the planes of bedding to a horizontal surface were clearly visible and easily measured. The direction of the strike was not, however, ascertained.

† Another specimen in my possession bears a close resemblance to *Rhynchonella boloniensis*, characteristic of the Upper Devonian of the north of France and Belgium.

‡ M. Breton's description of the Devonian strata met with in the boring given in fig. 2, p. 906, might pass for that of the Tottenham-Court-Road specimens. He says, "Ce sont d'abord des schistes rouges, puis des grès schisteux un peu micassés, bruns mélangés de vert, puis des marnes effervescentes vertes et rouges. . . . ensuite des schistes rouges, avec taches verdâtres, sableuses, fossilifères, contenant des plaquettes quartzites micassées très-dures," &c. ('Étude stratigraphique du Terrain houiller d'Auchy-au-Bois,' p. 39.)

This is especially the case on the south side of the great Coal-trough in the Liége, Mons, and Valenciennes Coal-fields. The Coal-measures are, all through these districts, greatly disturbed, thrown back on end, and not unfrequently reversed by the great disturbing axis of the Ardennes and Artois *.

A most remarkable instance of such a reversal has been recently brought to light in the Coal-works at Auchy-au-Bois near Lillers. As this is the most westerly point to which the Valenciennes coal-field has been traced under the Tertiary strata and the Chalk, and is the part of the basin nearest to England, I will briefly describe the circumstances of its discovery †.

Some years since the Coal-measures had been found to extend to near Bethune; but the many borings made further westward in the "Pas de Calais" were stopped either by the Mountain Limestone or by Devonian strata, so that further attempts were discouraged. In two borings at Auchy-au-Bois this was also the case; but the geological inferences from stratigraphical structure and organic remains were such as to lead the French geologists and M. Breton, the manager of the Company at that place, to believe that there was a reversal of the strata such as to render it possible that the younger strata might be found underlying the older.

Instead, therefore, of stopping the work on meeting with strata older than the coal, it was in this instance determined to continue. The result was as remarkable as it had previously been unexpected. In one boring (No. 15, fig. 2), the Devonian strata were reached at a depth of 131 metres, and at a depth of 168·30 metres the bore-hole passed, as was anticipated, into the *Carboniferous Limestone.* With the uncertainty, however, as to what might be the thickness of this formation, the bore-hole was not carried beyond a depth of 215·11 metres; but another bore-hole (No. 16, fig. 1) was commenced at a short distance to the north on the rise of the strata, and there, under the Cretaceous strata, at a depth of 148 metres, the Carboniferous Limestone was reached; at 170 metres the boring passed out of that formation into true *Coal-measures*, in which, at 185 metres, the bed of coal (*o*) was met with.

Another boring (No. 17, fig. 3) was then made further north, and there the Coal-measures were reached immediately beneath the "Tourtia," at a depth of 146 metres. A shaft was then sunk between the last two borings. As was expected, the Carboniferous Limestone was met with at a depth of 146·44 metres, which by its fossils (*Spirifer mosquensis*, *Athyris Roissyi*, *Rhynchonella pentatoma*, &c.) M. Breton identifies with the lower division of that formation—the "Calcaire de Tournay." These beds had a dip of 33° south, and extended to the depth of 155·40 metres, when a very acute fault was traversed and the Coal-measures reached—the latter consisting of

* See the sections given in my report "On the Probability of finding Coal in the South of England," &c., p. 161. Royal Commission on Coal Supply, 1869.

† This has been described by M. Breton in his "Étude sur le prolongement au sud de la zone houillère du Pas-de-Calais," Annales de la Société Géologique du Nord, tome iv. p. 138, 1876–77, and his 'Étude stratigraphique.'

Figs. 1 and 2.—*Sections of Borings at Auchy-au-Bois, near Lillers (Dépt. du Pas-de-Calais).*

Fig. 1 (No. 16).

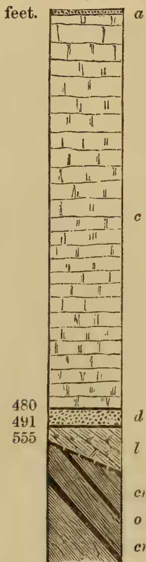
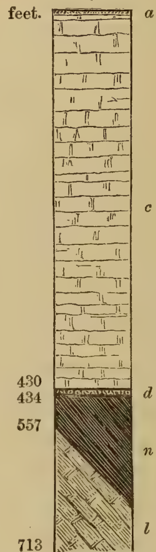
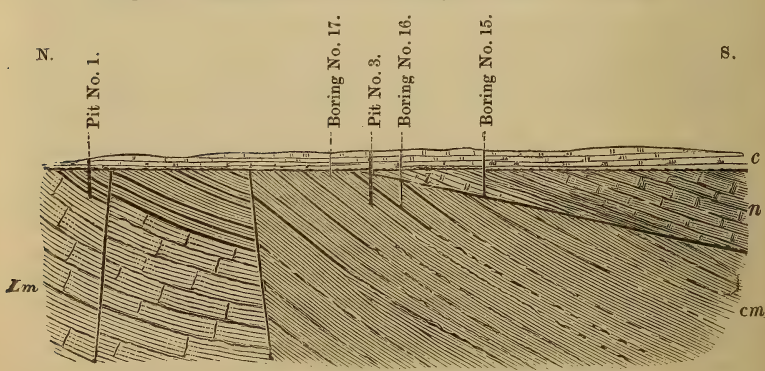


Fig. 2 (No. 15).



a. Gravel.
c. Chalk.
d. Tourtia.
n. Devonian strata.
l. Carboniferous strata.
cm. Coal-measures.
o. Coal-seam.

Fig. 3.—*Section across the Auchy-au-Bois Coal-field.*



c. Chalk.
n. Devonian.
l. Lower Carboniferous strata.
cm. Coal-measures.
Lm. Carboniferous Limestone.

shales and sandstones, with impressions and casts of the usual plants. At 167 metres a bed of coal, somewhat impure, but yielding large blocks, was come upon; its dip was 41° S.*

M. Breton explains these phenomena on the supposition that there is here a great fold of the Coal-measures enclosed between strata of Carboniferous Limestone, and that the Devonian strata pass over them by means of a reversal, accompanied by a fault and thrust, which has caused those beds to slide, as it were, over the Coal-measures at a very small angle. Fig. 3 is a generalized section of this singular Coal-field reduced from the sections and particulars (omitting some of the details) given in M. Breton's papers.

One great point of interest which the Auchy-au-Bois Coal-field presents is to be found in its relation to the probable extension of the Coal-measures under the same Cretaceous strata in England, and the light it throws upon the age of the Hardinghem Coal-field.

Sir R. Murchison and Mr. Godwin-Austen considered this latter coal-field, which lies between Calais and Boulogne, to belong to a lower and more unproductive part of the Carboniferous series than the Belgian and Valenciennes field; and this view I adopted in my Report in 1869. From subsequent examination of that coal-field, I am now satisfied that the view taken by M. Gosselet† is the correct one, and in this my friend Mr. Godwin-Austen also now agrees.

According to M. Gosselet, the Hardinghem Coal-field is a prolongation of that of Valenciennes. He proves it both by the lithological characters of the strata, by their organic remains, and by physical structure. Later observations at Auchy-au-Bois also show that the Coal-measures at Hardinghem are exactly on the prolongation of the strike (about E. 30° S., and W. 30° N.) of the Auchy-au-Bois trough; though west of Auchy-au-Bois there is an apparent thinning out of the fold that leads to the supposition that the coal-strata are not continuous between the two places, but form separate basins.

The prolongation of the same strike and accompanying boundary faults across the Channel would place the southern boundary of any coal-field under the Tertiary and Cretaceous strata of South-east England on a line which would pass a little south of Maidstone, whence it would cross the Thames obliquely, and range a short distance north of London. It must be remembered, however, that although such strikes and such faults may maintain a certain mean average direction, they are liable to considerable deviations, so that any underground Coal-measures, if there, may be either somewhat to the north or to the south of this line; but it is nevertheless on or near this line that they should be first sought for. Their exact course can only be determined by experiment.

It is, in any case, of the highest interest to find that we have

* At the time we visited the pit the works had been carried deeper, and they were working a fine seam of coal, which in places was 4 metres thick.

† "Étude sur le Terrain Carbonifère du Boulonnais," Mém. Soc. des Sc. Agr. &c. de Lille, 3rd ser. vol. xi. 1873: see also M. Gosselet's various papers in the Annales de la Soc. Géologique du Nord.

under London a succession of strata of the same character as those met with in connexion with the Coal-measures of the north of France and Belgium; and we are confirmed in the hope I have before expressed that, to the north of the line just named, productive coal-basins of similar character may be met with underlying the Chalk and Tertiary strata of this country.

The attempt to determine the strike of Devonian strata at Messrs. Meux & Co.'s was not successful; but the general direction of the strata has been proved by the last deep boring at Crossness, near Blackwall, undertaken by the Metropolitan Board of Works. In this instance the Chalk and Gault were successfully traversed, when, in place of the Lower Greensand, mottled red, grey, and greenish hard sandstones and red, slightly calcareous, clays were met with; but, owing to the small size of the bore-hole, the specimens were so fragmentary and, as in the case at Kentish Town, so much mixed with débris and fossils from the Gault and Chalk, that their determination was for a time difficult. After, however, inspecting various specimens obtained in passing through the 60 feet of these strata, and eliminating all the sources of error, I have now no doubt of the identity of the beds with those at Kentish Town. This would indicate a strike somewhere between N.W. and S.E., or W.N.W. and E.S.E., corresponding with that of the Palæozoic rocks in the north of France. A section of Crossness well, for which I am indebted to the courtesy of the Board, is annexed (p. 913).

In considering this question, it must be borne in mind that whatever the relative position of the Devonian and Coal-strata may be, there is one circumstance relating to their occurrence in this part of England that is here likely practically to limit the winning of coal. If, as we believe, the Lower Greensand extends underground from its outcrop in Kent and Surrey as far as London, its presence in that area would present a most formidable barrier to the sinking of shafts to the Palæozoic strata, owing to the difficulty of passing through any great thickness of loose sands so highly charged with water and under such a pressure. To the north of London, where the Chalk and Gault rest directly on the Palæozoic rocks, this impediment does not exist; but how far the same order of superposition may be maintained can only be determined by trials in various places. The zone marked by the absence of the Lower Greensand cannot be many miles in width, as this formation reappears, although in less force than in Kent, from beneath the Gault in Buckinghamshire and Bedfordshire, 30 to 40 miles north of London, and may be prolonged under part of the Chalk hills of those counties and possibly of Hertfordshire.

This brings me to the *second* point of importance determined by Messrs. Meux & Co.'s well. Although the well at Kentish Town had unexpectedly disclosed the existence of Palæozoic strata directly under the Gault, I have always felt convinced that the Lower Greensand, so thick at Sevenoaks and Redhill, extended to or near to London, and that although the Tottenham-Court Road appeared to me too near Kentish Town for a successful trial, I considered that water-bearing Greensand-beds might be found under Croydon or Sydenham, or possibly still nearer London* ; for with strata 400 to 500 feet thick at Redhill, indicating a deep-sea basin without any appearance of the proximity of land, it is evident that the shores of the old Lower Greensand sea were some distance off. There is there no evidence, as there is at Faringdon and in Cambridgeshire, of the proximity of a shore-line. The only question was how far north of Redhill and Reigate it might be.

This has now been settled by the section of the Tottenham-Court-Road well. At Kentish Town there was no trace of any Lower-Greensand beds. At the Tottenham Court Road, on the contrary, they have not only set in, but have attained a thickness of 64 feet. The character of the few fossils indicates waters of small depth; while the abnormal character of the strata is probably due to the existence of calcareous strata of Devonian (or Carboniferous ?) age in the adjacent cliffs or shore of the old Palæozoic land. It is to these that we must look for the origin of the calcareous matter which has replaced in greater part the loose quartzose and ferruginous sands of the Lower Greensand ; for on that old shore we might look for springs such as are now met with off many limestone coasts, where the shore-sands are converted into compact shelly limestones by the action of freshwater springs highly charged with carbonate of lime derived from the adjacent lands.

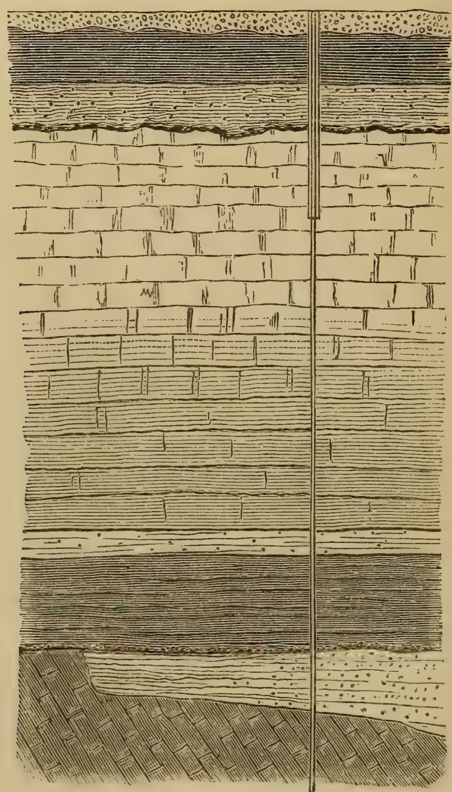
This old shore-line must lie somewhere between the south end of Tottenham Court Road and Kentish Town ; and the section between the two places may be represented by the following diagram, in which the Lower Greensand is assumed to end against an old underground cliff (fig. 4).

But whatever the origin and character of these Lower Greensand beds at this well, they must merge or pass into the great beds of quartzose sands, with their intercalated zone of Ragstone, which crop out from beneath the Gault at the foot of the North Downs ; and from the development which the formation has already attained in the short distance between Kentish Town and Oxford Street, it is probable that, with continued increasing dimensions, the sand-beds set in at no great distance to the south, and that therefore *the Lower Greensand* will be there found in the permeable condition necessary to store and transmit underground waters.

This surmise has been to a certain extent realized on the same line of country by the Artesian well recently sunk, at my suggestion, with much enterprise by my neighbour H. Bingham Mildmay, Esq., of Shoreham Place, near Sevenoaks, and which, so far as meeting with the Lower Greensand at about the estimated depth and obtaining a supply of water therefrom, proved successful. Mr. Mildmay's residence stands in the valley of the Darent, 12 ft. above the level of the stream, 5 miles north of Sevenoaks, and 2½ miles distant in a straight line from the outcrop of the Lower Greensand. The level of the surface above the sea is 194 ft. and of the Greensand at its lowest point of outcrop about 225 ft. A shaft 25 ft. deep was first

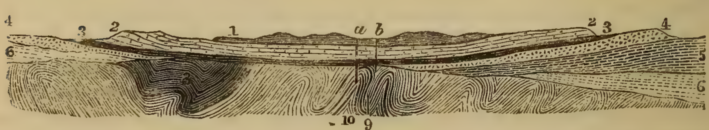
* "Anniversary Address for 1872," Quart. Journ. Geol. Soc. vol. xxviii. p. lx.

Fig. 4.—*Probable Section between Kentish Town and Oxford Street.*



a. Gravel.
b. Clay.
c. Lower Tertiaries.
d. Chalk.
d'. Chalk marl.
e. Upper Greensand.
f. Gault.
g. Lower Greensand.
h. Devonian.

Fig. 5.—*Diagram Section from the North Downs to London.*



1. Tertiary strata.
2. Chalk.
3. Gault.
4. Lower Greensand.
5. Wealden.
6. Jurassic strata.
8. Carboniferous strata.
9. Upper } Devonian strata.
10. Lower } Devonian strata.

a. Kentish-Town Well. *b.* Tottenham-Court-Road Well.

sunk, and then a bore-hole was carried down the rest of the way. The section obtained was as under*:—

	ft.
Soil and Chalk rubble	13
Chalk without flints (very hard)	112
Chalk marl (very argillaceous)	88
Upper Greensand	10
Gault	226
Lower Greensand (sand and sandstone)	26+
	475

On reaching the Lower Greensand the water rose in a trial-pipe fixed into the bore-hole to a height of 12 ft. (or rather more) above the surface of the ground. But unfortunately, from the loose character of the beds and the small size of the bore-hole, it got largely filled with the sand, and the delivery of water has consequently always remained very slow and small. Added to this, the water is slightly ferruginous and, with the slow discharge, has shown but little improvement; still, after settlement, it is quite potable.

The experiment is nevertheless one of great interest, and the result would, there can be no doubt, have been far more successful could the tubes be properly cleared of sand. The thickness of the Gault is unusual.

Combining the several data now in our possession, the accompanying section (fig. 5) shows the probable position and range of the *Lower Greensand* and the position of the *Palæozoic rocks* under the London Basin.

In short, while there is every reason to hope that, on the south of London, we may yet find in the *Lower Greensand*, beneath the Tertiary strata and Chalk, a source of large and valuable water-supply for metropolitan purposes, there is strong reason to believe in the probability of the discovery to the north of London of *Carboniferous strata*, including possibly productive Coal-measures, under the same Cretaceous formations †. The position assigned to the latter in the diagram is merely hypothetical. Even if the beds at Kentish Town are lower in the series than those of Messrs. Meux & Co.'s boring, the Palæozoic strata are so disturbed and folded that neither the dip nor the relative position of the Devonian beds afford any certain guide to the position of the Carboniferous trough.

It is to be hoped that the accuracy of the geological hypothesis may ere long be tested by a series of carefully considered and systematic trial-borings in the neighbourhood of London, and the solution of these two important problems effected.

* The boring was made by Messrs. F. R. Baker and Sons, to whom and Mr. Mildmay I am indebted for these particulars.

† The westward prolongation of this underground belt of Palæozoic strata is not only indicated by the various pebbles of crystalline and metamorphic rocks met with in the Lower Greensand, and by the shore-conditions of this formation at Faringdon, but also by the apparent presence of the Trias under the Great Oolite at Oxford (as suggested by the author in a paper "On a Mineral Spring at Oxford," Proc. Ashmolean Soc. for 1876); while the existence of the Coal-measures themselves has recently been proved under the Jurassic series and the Trias near Burford, on the confines of Oxfordshire and Gloucestershire.

Section of the Artesian Well at Messrs. Meux & Co.'s Brewery, Tottenham Court Road, London.

Depth.	Particulars of Well-section.	Thickness.	Geological Formation.	Thickness.
ft.	Flint Gravel	21 ft.	For details of these beds see Mr. Whitaker's "Geology of the London Basin," Mem. Geol. Surv. vol. iv. p. 525	156½ ft.
	London Clay	63½		
	Woolwich and Reading beds	51		
156½	Thanet Sands	21		
603½	White Chalk, with flints more or less plentiful; a few fine seams of grey clay in the lower part, and fossils often numerous, especially in the lines of bedding	447	Middle Chalk	655½
	Compact light grey Chalk, with few fossils. *Inoceramus*	176½	Lower Chalk	
812	Grey Chalk-marl, with *Inoceramus Cuvieri* and *Ammonites varians*	32	Chalk Marl	
840	Micaceous light grey Sandstone, very slightly calcareous (firestone). *Ammonites splendens*. Green and quartzose sand	28	Upper Greensand	28
	Calcareous bluish-grey clay, with a few seams of calcareo-phosphatic nodules. *Ammonites splendens*, *A. lautus*, *Inoceramus concentricus*, *I. sulcatus*, *Dentalium medium*, *Belemnites ultimus*, and wood	157	Gault	160
	Greensand and clay	2½		
1000	Seam of calcareo-phosphatic nodules and quartzite pebbles	½		
	Light-coloured limestone	1	Lower Greensand	64
	Seam of quartzite pebbles	½		
	Sandy limestone	3½		
	Light-coloured limestone; traces of fossils	29		
	Marly sand	1		
	Light greyish limestone, with angular grains of quartzose sand and a few specks of chlorite and mica. Numerous casts and impressions of shells:—*Cardium Hillanum*, *Trigonia alæformis*, a small *Cerithium*, Corals, and Foraminifera	24		
	Light grey oolitic-looking rock	2		
1064	Rubbly stone and clay	3		
1144	Mottled red, purple, and light green shales, very finely micaceous, and with well-preserved fossils in places; dips at an angle of 35°; a few thin seams of red and grey quartzite	80	Upper Devonian	80+

Section of second Well-boring at Crossness (on the south bank of the Thames below Blackwall), 1050 yards south of first boring.

	Particulars of Well-section.	Depth to top of each bed *.	Geological Formation.	Thickness.
				ft.
1.	Soil	+ 3·60 ft.	Alluvial beds	21
2.	Dark brown stiff clay	+ 2·60		
3.	Blue silty clay	− 1·15		
4.	Peat	− 4·98		
5.	Blue silty sand	− 11·40		
6.	River drift gravel	− 17·40	Quaternary	18
7.	Very hard stiff blue clay	− 35·40	Woolwich and Reading beds	47
8.	Stiff yellow clay and sand-layers	− 37·90		
9.	Hard grey sand, intersected with layers	− 39·40		
10.	Layers of tenacious clay of various hues and shells	− 47·85		
11.	Hard sand, with layers of clay	− 49·90		
12.	Stiff hard sandy clay	− 51·15		
13.	Very hard stiff sandy clay	− 54·90		
14.	Dark tenacious sandy clay	− 56·56		
15.	Very stiff hard clay	− 60·15		
16.	Dark green sand	− 62·15		
17.	Ditto and shells	− 63·65		
18.	Shell-bed	− 64·24		
19.	Dark green sand, with round pebbles of various sizes	− 66·15		
20.	Ditto, but no pebbles	− 69·90		
21.	Green clayey sand	− 70·40		
22.	Ditto and pebbles	− 72·40		
23.	Ditto and few pebbles	− 73·40		
24.	Ditto	− 76·40		
25.	Greenish-grey sand and pebbles	− 77·40		
26.	Thanet sand	− 82·40	Thanet Sands	50½
27.	Layer of flints on top of chalk	− 132·90		
28, 29	Chalk and few layers of flint & rock Chalk-marl	......	Middle and Lower Chalk	637½
30.	Upper Greensand	− 764·40	Upper Greensand	65 †
31.	Gault clay	− 829·40	Gault	176
32.	Gault clay, full of stones, shells, pyrites	......		
33.	Top of Red Sandstone and bottom of Gault. Hard red rock-shale. Micaceous	− 1004·4	Old Red Sandstone or Devonian	60
34.	Very hard grey rock. Micaceous	− 1012·4		
35.	Dark-red argillaceous shale rock	− 1016·4		
36.	Very hard quartzose red and grey rock	− 1023·4		
37.	Very hard quartzose greenish-grey rock	− 1030·9		
38.	Light-red shale	− 1038·4		
39.	Greenish-greyish shale	− 1040·4		
40.	Very sharp grey sand, with black grains	− 1044·4		
		− 1056·4		

* These depths have reference to Ordnance datum = 12·50 feet below T. H. W.

† This should probably be reduced, and the thickness of the Chalk increased.

53. Notes *on the* Palæontology *and some of the* Physical Conditions *of the* Meux-Well Deposits. By Charles Moore, Esq., F.G.S. (Read June 19, 1878.)

The various deep borings which have been put down at Crossness, Harwich, Kentish Town, and more recently at Meux's Brewery, in the Tottenham Court Road, have amply established the correctness of Mr. Godwin-Austen's deductions that a ridge of Palæozoic rocks passes under the Jurassic and Cretaceous beds of the south-east of England, the probability, if not the certainty, being that the rocks of which that ridge is formed are a continuation of those which skirt the South-Wales coal-basin, and which, in passing through Somersetshire, are continued in the Mendip range until lost under Secondary deposits near Frome.

In the above districts I have previously pointed out that the representatives of some of the Secondary beds are found associated with the older rocks, under very peculiar conditions, through a line of country from east to west of about sixty miles. At one spot thin deposits or pockets of Inferior Oolite may be seen lying unconformably upon the highly inclined but planed down edges of the Carboniferous Limestone; at another, conglomerates of Liassic or Rhætic age of a few feet in thickness, some of them exhibiting shore-conditions, may be found filling depressions in the limestone or passing down its vein-fissures; and however thin these deposits may be, they can be recognized as distinct, and as representing on the sides or otherwise of the southern portion of the Palæozoic anticlinal the presence in the district of Rhætic, Liassic, and Oolitic formations.

Perhaps the most interesting evidence of these peculiar physical conditions is seen where the Carboniferous Limestone for the last time presents itself on the east of the Mendips, before passing under the thick deposits of Oxford and Kimmeridge Clays and the Cretaceous beds of the Wiltshire Downs not far beyond. Within a few square yards in a roadside quarry at Marston, near Frome, are exhibited stratified beds of Inferior Oolite, a dense variegated conglomerate of Liassic age with many organisms, and a thin band of Rhætic clay, all resting on Carboniferous Limestone which shows itself in the bottom of the quarry; whilst passing from the Lias down through the limestone is a mineral vein, some feet in thickness, filled with calc spar; and close at hand in the same quarry are evidences of two caverns, possibly containing Mammalia of the Cave period.

Seeing that the above conditions are frequently present, especially on the southern boundary of the Palæozoic ridge, and believing that after its disappearance at Marston road it passes under the south-eastern districts of England, there seemed to me no reason why, in connexion with some of the deep borings, there might not be some evidence, or a trace at least, of similar unconformable conditions of deposit, though altered possibly by physical changes that might present themselves, by the distance or depth, as compared with the Mendips, at which the later beds met the Palæozoic barrier.

Even though no distinct stratified beds might be recognized, in such a case as the Meux brewery, between the well-known Cretaceous beds, seemingly putting on throughout their general normal conditions, and the Devonian series, it might still be possible by close and careful examination to find some evidence of the former presence either of denuded deposits or of others still resting not far off on either flank of the Palæozoic ridge, washed into and mixed up with the later horizontal deposits by which it was subsequently covered. It should, however, be borne in mind, in case of failure, that, as compared with the surrounding geological area, the diamond borer yields but an infinitesimal point of but a few inches in diameter for examination, thereby rendering the proof uncertain and doubtful as to alighting upon the right spot for derived material, or for finding an occasional intercalated unconformable deposit.

I was unable to give any consideration to the boring operations at the Meux well during their progress, but was subsequently obligingly supplied by the authorities with the following samples, selected promiscuously by the brewery engineer, who furnished their depths from the surface :—

Depth of core. feet.	
509. 596. 688. 716.	White chalk, unexamined.
800.	Light-blue clay ; vegetable remains, Ventriculite markings, and fish-scales on surface.
820.	Greensand, dense and micaceous.
876.	Gault, a finely laminated blue clay, with many Microzoa.
899.	Do. do., with vertical pipes filled with pyrites and organisms often covered with the same Mineral.
914.	A grey indurated stone or marl, with vegetable markings and fish-scales on surface.
1000.	A blue coarse marl, with chloritic grains and small nodules of phosphate of lime.
1005.	A compact oolitic limestone, with fragments of shells.
1018. 1024. 1031. 1044. 1050. 1057.	Coarse grey marl, some samples more indurated than others, and most of them containing numerous granules of a darker colour, also free oolitic concretions and many organisms.
	Devonian beds.

Though the samples sent me were from uncertain intervals, it could be observed that the beds passed through down to the depth of 1000 feet presented the general lithological characters of their representatives elsewhere, the exception perhaps being that at intervals there were intercalated beds of oolitic limestone, which, but for their density, might have passed for great deposits of Oolite, and would have furnished a first-rate building-material for the great city, could they be made available. I am not aware that any equivalent beds have been met with elsewhere in any of the Cretaceous outcrops; but possibly, like the Great Oolite, they may not have been continuous over a large area. Their presence shows an interruption or change of deposition from some physical cause, and probably intervals of time between succeeding beds.

There are only two sources from which to obtain any evidence regarding the physical conditions which prevailed under London, as revealed by the Meux well-boring:—first, from the petrology of the materials passed through; and, secondly, from a study of their organic contents. Beyond their palæontology, I have nothing to remark in the beds from the Gault upwards.

As regards the first head, the deposits from about 1000 feet downwards to the Devonian shales have been very properly decided to represent one of the periods of the Lower Greensand; but it belies its name, for it is throughout entirely calcareous. I have been unable to trace any distinct line of stratification or bedding therein. It puts on the look of a roughly granular or slightly conglomeratic marl, such as might have been deposited in hollows or basins, and subject to the influence of currents of water passing over it, whereby it would be again disturbed and redeposited. It is grey in colour, with a slight blue tint, caused by an admixture of the débris of a darker bed, which I at first thought was phosphate of lime or chloritic grains, but which, like the rest of the deposit, proved to be calcareous. A familiar comparison for the deposit between the Gault and the Devonian would be that of coarse dried builder's mortar. Its lithological aspect led me to anticipate that there would surely be mixed up with it some records from the long interval between the Cretaceous and the Palæozoic periods; but with the following exceptions, one of which is of some interest, my examination for derived material was unsuccessful. Even the surface of the Devonian beds seems to have been so thoroughly cleansed of loose matter of its own age before the deposition of the Neocomian deposits above, that not a grain could be detected mixed therewith. The specimens which, from their character, I have little doubt are derived, are some small irony-looking grains of quartz, several grains of what appear to be sulphate of barytes, a minute flake of carbonate of copper, and several small grains of coal. Regarding the latter, it was not to be expected that the borer would be fortunate enough to pass through an erratic boulder of coal like that found in the Chalk near Dover some time since, nor would there be any need; for however small the fragments, they equally imply the possibility of coal somewhere in the district. It is much to be regretted that other confirmatory evidence could not be obtained on this point. Whence these fragments come, whether from true Carboniferous beds present along the Palæozoic anticlinal, or from Secondary deposits like those mentioned by Professor Judd, in Quart. Journ. Geol. Soc. 1871–3, as occurring in Spain in beds which in time may be represented by those in the Meux well, must be a matter for conjecture.

Palæontology of the Well.

The Chalk.—I did not examine the Chalk cores, and have only to remark that on the surface of one I noticed that the borer had cut in two a specimen of *Dercetis elongatus*, a well-known fish of the Upper Chalk.

The Upper Greensand.—From this horizon I obtained only one small sample. As it yielded the following remains, including two new species of Entomostraca, it might have repaid further examination:—

Cristellaria acutauricularis.	Cythere virginea, *Jones.*
—— rotula.	—— concentrica, *Reuss.*
Nodosaria raphanistrum.	Cytherella Münsteri, *Röm.*
Echini spines &c., several species.	Paracypris ?, nov. sp.
Cythere, nov. sp.	Cuttle-fish hooks.

The Gault.—Organic remains of any size do not appear frequent in these beds, though I noticed that several cores were put aside at the brewery with Ammonites and *Inocerami*. Vegetable remains were tolerably abundant; amongst these were some jointed stems, not unlike *Baieræ*, but too imperfect for identification. The chief interest of this section of the boring arises from its Microzoa, especially its Rhizopoda, the few samples I had having yielded about 19 genera and upwards of 30 species. Amongst these *Bulimina* and *Cristellaria* are plentiful. Notwithstanding the myriads of *Globigerina* in the Chalk, I have found only a single specimen in all my gatherings.

The Entomostraca are also very abundant, of about thirteen species; and rarely there are single scutes of *Scalpellum*. The univalves are represented by a few species of *Turbo* and *Turritella*, covered with iron pyrites and too small to determine; and amongst the Cephalopoda I have met with a curious but perfect *Hamites* about the 30th of an inch in diameter. There are a few small vertebræ and ribs and teeth of small fishes, and a portion of a more elongate vertebra, which may be reptilian. The specimens from the Gault are usually in good condition and of marine species.

The whole of the Entomostraca have been revised by Professor T. R. Jones. In the list he gives in the Geol. Mag. 1870, vol. vii. pp. 74–77, he enumerates 28 British species from Cretaceous and Neocomian beds. It is satisfactory, therefore, that from the beds below the Chalk in the well-section I have obtained as many as twenty species, four of which are new.

Fossils from the Gault.

Vegetable stems, Baiera ?	Dentalina communis, *D'Orb.*
Spongia ? Ventriculites.	Frondicularia complanata, *Defr.*
Bulimina Preslii, *Reuss*, abundant.	—— strigillata.
Cristellaria rotula, *Lam.*, do.	—— species.
—— cultrata, *Mont.*	Globigerina cretacea, *D'Orb.*
—— acutauricularis, *Ficht. & Moll.*	? Haplophragmium inflatum, *Reuss.*

? Lagena lævis, *Walker*.
Marginulina raphanus, *Linné*.
—— tenuissima, *Reuss*.
? Nodosaria prismatica, *Reuss*.
—— raphanistrum, *Linné*.
—— tetragona.
Nummulite ?
Planularia arguta.
—— pauperata.
Planorbulina ammonoides.
Pleurostomella fusiformis, *Reuss*.
Pulvinulina caracolla, *Röm*.
—— sp.
Quinqueloculina, sp.
Textilaria agglutinans, var. parallela, *Reuss*.
—— (Proroporus) Schulzei, *Reuss*.
Trochammina incerta.
Vaginulina recta.
—— truncata.
Verneuilina triquetra, *Münst*.
—— Bronni, *Reuss*.
Smilotrochus.
Ophiura, joints of.
Scalpellum magnum, scutes and rostral latus.
Crustacea, claws of.
Cythere ornatissima, *Reuss*.
—— quadrilatera, *Röm*.
Polycope, sp.
Macrocypris ? arcuata, *Münst*.
? Cytheridea perforata, *Röm*.
Cytherella ovata, *Röm*.
—— Münsterii, *Röm*.
—— Beyrichii, *Reuss*.
—— Williamsonii, *Jones*.
Cythere concentrica, *Reuss*.
—— quadrilatera ?
Paracypris ? gracilis, *Jones*, sp.
Pecten.
Pinna.
Ostrea.
Various small univalves.
Turbo, sp.
Hamites.
Fish remains.
Coprolites, with scales, &c.

The Lower Greensand and Lacustrine Deposits.—Beds of oolitic limestone intervene between the Gault and the 50 feet of Cretaceous deposit lying above the Devonians. Whilst lithologically this differs from the Gault, a greater change takes place in its palæontology; and there is probably an unconformability between these two Cretaceous divisions. On looking at the samples in block, few remains are visible; but by dissolving and washing the least indurated portions many organisms are released from a limy coating, which passes off with the water, and the deposits are then found to be half composed of them. Prominent amongst these are many joints of *Pentacrinites Fittoni*, plates and spines of *Echini* of several species, joints of *Ophiura*, plates of *Marsupites*, valves of Cirripedia, &c., all of which are dismembered; and all other genera of any size seem to be very fragmentary. In contrast with the Gault, which yielded so many Rhizopoda, only four genera occur—and these, except *Carpenteria* referred to below, species recurrent from beds as low as the Lias; many Entomostraca and very small crustacean claws are plentiful, and Polyzoa equally so; but of corals I have found only a single fragment. *Terebratulæ* occur either as fry or dwarfed specimens; *Rhynchonella latissima* is usually crushed; also *Thecidium* and *Zellania* hereafter mentioned. The Conchifera are few in number, and from their worn and fragmentary state are in an unsatisfactory condition for specific identification. The same remark applies to the Gasteropoda, of which there are about twenty genera; many of them are very dwarfed, and show such signs of rolling and abrasion as to render them unrecognizable. Some of them, especially the Cerithiidæ, which are numerous, whilst being carried about as dead shells by the water of the period, have become encased in a tufaceous covering of carbonate of lime which entirely conceals their shells.

Lower Greensand.

Coal, fragments of lignite.
Carpenteria.
Cristellaria rotulata, *Lam.*
—— acutauricularis, *Ficht. & Moll.*
Marginulina calliopsis.
Vaginulina legumen, *Linné.*
Planularia pauperata, *P. & J.*
Planorbulina ammonoides ?
Saccammina ?
Haplostiche fœdissima (Lituola Soldanii).
Marsupites, plates of.
Pentacrinites Fittoni.
Crinoid stem.
Asteriidæ, joints of.
Echinidæ, plates, spines, &c.
Serpula.
Crustacean claws, several sp.
Bairdia Harrisiana, *Jones.*
—— subdeltoidea, *Münst.*
—— angusta.
Cytherella compressa, *Münst.*
—— beyrichii, *Reuss.*
Cythere interrupta, n. sp.
—— concentrica, *Reuss.*
Cytheridea perforata, *Röm.*
Diastopora, sp.
—— sp.
Polyzoa, sp.
Entalophora.
Spirophora ?
Pustulopora, sp.
Alecto dichotoma ?
Defrancia ? or Lichenopora ?
Terebellaria ?
? Isastræa Morrisii, *Duncan.*
Cirripedia, several sp.
Rhynchonella latissima.
Terebratula ovata ?, young.
Terebratula, sp.
Discina.
Thecidium triangulare.
Zellania neocomiensis, *Moore.*
Avicula pectinata, *Sow.*, young.
Exogyra Boussingaultii, *D'Orb.*
—— sinuata ?
Lima, sp.
Pecten, fragments.
Astarte formosa, *Sow.*
Nucula impressa, *Sow.*
—— planata, *Desh.*
Tellina ?
Potamomya ? Corbula ?
Venus parva, *Mant.*
Arca, sp.
Vicaria ?, young forms.
Cerithium ? or Potamides ?
Delphinula ?
Emarginulina neocomiensis, *D'Orb.*
Hydrobia ?
Valvata ?
Natica.
Neritina.
Nerinæa.
Chemnitzia.
Pleurotomaria.
—— or Solarium.
Turbo, sp.
Pyrula.
Trochus.
Potamides ?
Tornatella.
Rissoa.
Various univalves.

The Polyzoa have been obligingly examined by Mr. Etheridge, jun.

Extension of Generic Life.—It was scarcely to be expected that from the examination of a few pounds of material brought up from a depth of 1050 ft. under London any light could be thrown on the existence in time of any organic remains ; but such is the case with the following genera. The Neocomian beds of this country have hitherto yielded but one *Thecidium*, the *T. Wetherellii.* This genus had its chief development in the Oolite. The *T. triangulare* is one of the commonest forms, and I have shown that it ranges from the Lower Lias to the Coral Rag. Four examples of this species come from the well. Like the former, I have traced the minute and rare genus *Zellania* through the same Secondary beds, though only the 40th of an inch in diameter; five specimens have occurred, the interior of one showing the characteristics of this genus. Still more interesting is the extension in time of one of the most remarkable of the Foraminifera, the genus *Carpenteria*, which has hitherto only been found recent in the seas of the South Pacific, the West

Indies, &c. Its complete structural history we have been a long time in learning. It was first noticed by Dr. Gray in the 'Annals of Natural History' in 1858. A fuller description was given by Dr. Carpenter in his 'Introduction to the Foraminifera' in 1862, and subsequently it has been the subject of several papers in the 'Annals of Natural History' by Mr. Carter. It has usually been found as a conical body attached to the surface of corals and shells by a broad base, having at the apex a central rounded aperture. In the above work for July 1877 Mr. Carter has figured a more perfect example, in which it is seen that the apex had a tubular spinose extension, which bifurcating occasionally, passed into brush-like processes. Owing to their extreme delicacy they had hitherto been broken off. Though the shell itself has not yet been found, four of these tubular continuations come from the well. They are less than the fiftieth of an inch in diameter, but are sufficient to show the presence of *Carpenteria* in Neocomian times. They have been examined by Mr. Carter, who remarks that they differ from any he had yet seen in the scattered foramina being also prolonged into smooth, straight, conical elongated points, which was probably one of the characteristics of the species. A single cell appears to indicate the presence of *Saccammina* in this deposit*.

In the early stages of my examination I had noticed the terrestrial or freshwater indications presented by some of the shells, and forwarded a series of minute univalves to Dr. Gwyn Jeffreys, who expressed the opinion that (though he could not recognize any land shells) many of the others were such as would be the inhabitants of fresh water or swampy deposits, and that amongst them were probably the genera *Hydrobia*, *Valvata*, and *Cerithidea*.

Being aware of the intimate acquaintance possessed by Mr. C. J. A. Meyer with the fauna of the Cretaceous beds, he kindly allowed me to send him a few of the most unrecognizable specimens, some of which he confessed, from their condition, were beyond his powers. He was impressed with the evident mixture of species, and thought that some of them bore a closer resemblance to freshwater Wealden than to truly marine genera; that the *Cerithidea* were very like the young of the Punfield *Potamides*, whilst some other very young univalves resembled the brackish-water *Vicaria*; and that amongst the worn bivalves he recognized either *Corbula* or *Potamomya*. Regarding *Cerithium* it is interesting that Mr. Meyer should have remarked, in his paper in the Quart. Journ. Geol. Soc. xxviii. p. 248, 1872, when writing of a passage-bed from the Wealden into the Neocomian, that "the mode of its occurrence is peculiar: the shells are frequently eroded or waterworn as to their surface; they are often broken, and exhibit the appearance of having been washed or drifted into their present position,"—a description, as I have shown, equally applicable to the smaller Cerithiidæ from the Meux well.

In the whole, the cores examined have yielded me 160 species of

* As my friend Mr. Brady is preparing a monograph on the Cretaceous Foraminifera for the Palæontographical Society, he has kindly promised his critical supervision to the lists now given.

organic remains. In giving consideration to those which have been derived from the lowest 40 or 50 ft. above the Devonian, there appears little doubt that two *facies* can be recognized palæontologically, and I think, also (though there may not be much difference), as to condition, one group, and that the largest, will prove to be marine, and probably of the age of the Lower Greensand; the other group from fresh or brackish water, and though now obtained from the same deposit, implying that when living they must have been subject to different physical conditions, what those were being now only matter for speculation. The marine forms appear, though dismembered and fragmentary, to have been the least subject to erosion. Had they all been littoral or estuarine they would have been liable to the same amount of attrition; and it seems impossible that the delicate shells of the marine Microzoa could have undergone the rough treatment of some of the other remains without having been destroyed; the Entomostraca especially come out as detached shells, or in single valves, as sharp as when living.

I am most inclined to the view that the surface of the Devonian beds under London was occupied by shallow lacustrine basins, their waters having sufficient mechanical movement from streams or otherwise to cause the erosion of its many organisms. In the open quarry sections at Swindon of the freshwater Purbecks it may be seen, from the channelled character and want of continuity of some of the beds, that they must have been subject to repeated movements. Probably this was so with the beds under notice, until they were invaded and at last finally occupied by the seas of the Neocomian period. In this case the lacustrine deposits must have preceded those of the Lower Greensand, though probably not by a long interval. The precise stratigraphical horizon the former would occupy is, under the circumstances, difficult to determine.

Some difficulties have been experienced, and considerable time occupied, in working out the details of this necessarily imperfect paper. No doubt many interesting geological studies would present themselves along the line of the Palæozoic barrier as it passes onwards from the Mendips to the east at points where it is met by later deposits, could its surface be uncovered. In a former paper I pointed out that the elevatory force which had so great an effect upon the uplift of the Mendips was exercised from the south of the line of elevation during Triassic times, whereby the Palæozoic beds, including the Coal-measures, were carried forward to the north, their elevation in this direction preventing so thick a deposition of Secondary beds thereon; whilst it was shown by sections that there was a corresponding trough-like depression on the south, whereby the Secondary rocks were thickened, a fact which was probably fully illustrated by the experiment at Battle.

It is to be hoped that, on the occasion of another deep boring, the northern slopes of the Palæozoic barrier may be fortunately struck, and persevering scientific research have its full reward.

Discussion.

Prof. Ramsay said that as the South Wales coal-field, the Bristol coal-field, and the Forest of Dean coal-field were basins originally continuous, and only separated by denudation, Mr. Prestwich and himself had agreed before the Royal Coal Commission that coal-fields might exist below the Secondary strata to the eastward. The correctness of this opinion was proved by the boring put down by Mr. Fox at Burford, in Oxfordshire, which reached undoubted Coal-measures. Prof. Ramsay thought that one of these coal-fields might yet be found near London by penetrating the overlying Secondary rocks.

Prof. Seeley stated that in the supposed Triassic deposits of the Kentish-Town well he found a portion of a Belemnite of a form peculiar to the Neocomian. He referred to the numerous derived specimens of Carboniferous rocks and fossils found in the local Neocomian deposits of Cambridge, and to the absence of all traces of Devonian. He regarded the evidence of the Devonian age of the beds at the bottom of Meux's well as not perfectly satisfactory, owing to the imperfection of the specimens.

Mr. Whitaker remarked on the difference between the Lower Greensand at the outcrops north and south of London, and the peculiar oolitic limestone found in Meux's well. He regarded the beds at the bottom of the Crossness boring as by no means proved to be Devonian, but thought some of the specimens more closely resembled New Red Marl. He referred to the Loughton section, in which water was got at the base of the Gault, probably indicating the existence of Lower Greensand. He thought that, considering the inverted condition of corresponding strata in France and Belgium, the determination of the direction of the dip of the beds in Meux's well was by no means of great importance. He did not think that the depth of Gault at Shoreham was exceptional, as at Caterham and other points along the outcrop an even greater thickness of Gault had been found. He stated that the Cambridge phosphate-bed, a few inches thick, was found immediately above the Upper Greensand in Meux's well, and pointed out that some doubt existed as to the thickness of the several beds passed through in the boring.

Mr. Blake suggested that the bed above the Devonian might be derived from the denudation of Jurassic as well as of Neocomian deposits. He alluded to the evidence from *Thecidium* and *Carpenteria* as bearing on this subject, and stated that evidence of the presence of the latter had been obtained from Corallian deposits.

Mr. Champernowne suggested the possibility of the existence of Old Red Sandstone beds at the bottom of some of these deep wells.

Prof. Judd stated that the fossils of the oolitic beds at Meux's were shown by Mr. Etheridge and Mr. C. Moore to be undoubtedly Neocomian. He supported Mr. Whitaker's view as to the great thickness of the Gault at some points round the London basin.

Mr. Harrison pointed out the correspondence of the specimens from the Crossness boring with the typical Trias of the Midland district.

Mr. Evans referred to the undulations of the strata of the N.W. of France, as pointed out by M. Hébert, and to the parallelism of the river-valleys of that district, which corresponded in direction with the Bethune and Marquise coal-fields, and also with the general strike of the North Downs. He argued that these undulations were prolonged into England, even to the neighbourhood of London, but feared that the deposits covered such small areas as to give little hope of obtaining successful results from trial-borings.

Prof. Prestwich, in reply, said that he thought that the thinness of the Neocomian at Meux's well was due partly to the original smallness of the deposit and partly to denudation. He remarked on the abundance of carbonate of lime in the beds. He considered the beds at Kentish Town and Crossness to be Old Red Sandstone, from their agreement with the equivalent beds in the neighbourhood of Frome. He found that *Rhynchonella bollensis* occurred in Meux's boring, proving the beds to be Upper Devonian. He had watched the boring at Kentish Town very carefully, and did not think that any beds intervened between the Gault and the red micaceous sandstone and grits. The fossils found appeared, as at Crossness, to be all derived from above, as was determined at the time by both the late Mr. Sharpe and himself.

54. *On* Pelanechinus*, *a new Genus of* Sea-urchins *from the* Coral Rag. By Walter Keeping, Esq., B.A., F.G.S., Professor of Geology in the University College of Wales. (Read June 19, 1878.)

[Plate XXXIV.]

This is a Sea-urchin of more than ordinary interest, and remarkable for possessing an unusually developed system of overlapping plates around the mouth-opening. Such a structure is now well known in the deep-sea *Asthenosoma* (or *Calveria*), where it has been compared to the whole tests of some flexible Echini from the older (Palæozoic) rocks. I believe that the whole test of this Urchin also was flexible, though not nearly to the same astonishing degree as in *Asthenosoma*.

Dr. Wright, in 1855, described this species from very fragmentary portions under the name *Hemipedina corallina*†; but since that date the more perfect specimens described below have been found, and the characters seen in these demand their wide separation from *Hemipedina*, and establish a new genus whose affinities are rather with the *Echinothuridæ*.

I have only two specimens to work at, not being able to find those mentioned by Dr. Wright on page 164 of his Monograph (Pal. Soc.). Both of these are, however, very good. One was found by my father at Calne in 1866, and is now in the Woodwardian Museum, Cambridge: the other, from the same locality, is in the cabinet of Dr. Wright. They have been kindly lent to me for description.

I. The Woodwardian Museum Specimen.

The Woodwardian Museum specimen is a fine Urchin, 4 inches in diameter, with the whole of its oral hemisphere beautifully exposed (Pl. XXXIV. fig. 1). It is circular in contour, and has subsided, it may be by its own natural weight helped by subsequent rock-pressure, to the proportions of an ordinary plum bun. In the centre is seen the dental apparatus surrounded by a zone of scale-like actinal (mouth-membrane) plates; and more externally are the five ambulacral and five interambulacral areas of the ordinary Echinoid character.

All the plates are unusually thin, and all, including the squamous actinal plates, are covered with radiating *series* of tubercles. Spines are abundant, but small, only a few of the primary set being preserved.

The *interambulacral areas* (fig. 3) are broad and rapidly expanding (measuring $\frac{1}{2}$ inch at the oral extremity and $1\frac{3}{4}$ inch at the equator); each is ornamented with six or eight radiating series of primary tubercles of moderate size, which diminish slightly towards

* Πέλανος, a soft cake offered to the gods.
† British Fossil Echinodermata, Oolitic (Pal. Soc.), p. 163, t. xii. f. 1.

the mouth. The plates are very narrow and long, especially those at the ambitus, and are bounded not by straight lines, but by curved or gently undulating edges; the ambulacral edge is crenate, with three or four baylets. The plates do not overlap each other, but both the upper and lower edge of each plate are slightly hollowed.

The larger interambulacral plates bear three primary tubercles, whose areas extend almost to the edges of the plate; and also one or two smaller primary tubercles near the median and zonal lines of the (interambulacral) area. Numerous minute perforated tubercles, and still smaller granules, border the whole plate, form rings around the larger tubercles, and crowd the spaces between them. The plates near the oral pole bear three primary tubercles, and of these the central one is largest.

The *ambulacral areas* (fig. 2) are broad, and vary little in their course round the test; so that, while they are nearly as broad as the interambulacral areas at the oral extremity, at the equator they are scarcely more than one third as broad. On the non-poriferous zone are two ranges of primary tubercles, which are alternately larger and smaller. The plates also are alternately large and small, the greater being as broad, or nearly so, as the interambulacral plates, whilst the small ones are only half that size. A consequence of this difference in the plates is, that the usual zigzag line of junction of the ambulacral plates is not produced here, but the angle-end of each larger plate is truncated for the flat face of a smaller ambulacral plate in the other range opposite (fig. 5).

Every ambulacral plate carries one primary tubercle; and minute tubercles and granules are present here just as they are upon the interambulacral areas.

The poriferous zones are straight and rather broad (about equal to the non-poriferous zone), expanding slightly from the pole outwards. The pairs of pores (fig. 6) are surrounded by a prominent oval ring, which a slight depression renders double around the longer sides. Near the mouth the pores are arranged in double oblique pairs; elsewhere they are trigeminal. Minute tubercles and granules are scattered between the groups of pores.

The *actinal (buccal) area* is $1\frac{1}{2}$ inch in diameter (*i.e.* three eighths of the whole test), its circular outline being interrupted by ten broad and deep peristomial notches. Its centre is occupied by the broken ends of the jaws, and the rest of the area around these is covered with large squamous plates which overlap each other regularly towards the mouth (fig. 4). These bear tubercles in radiating series. The exposed surface of each plate is very long transversely (nearly as long as the breadth of the whole ambulacral area close by) and narrow, with rounded and irregular contours. Two or three primary tubercles are seen upon it which are smaller than those of the corona; and the minute tubercles and granules are also present, though less abundantly than elsewhere upon the test.

Only one third of each of these scale-like buccal plates (fig. 9) is exposed, and this part is nearly as thick as a coronal plate; but the overlapped portion gradually thins away to an edge.

Every one of these plates that is well exposed shows a pair of pores situated somewhat out of its centre, and surrounded by an oval ring. They are arranged roughly as a single series running from the mouth-opening in a line with the poriferous zones of the corona; but there is no marked difference in character except the presence of the pores themselves to define a poriferous and a non-poriferous zone upon this part of the test. If there are any plates here without pores, to correspond with the proper interambulacral areas of the corona, these must be small, and they may perhaps be absent.

The primary tubercles of this species (fig. 7) are proportionately small when compared with the size of the test. They are deeply perforated, and are elevated upon prominent bosses, which are expanding at the base, and smooth (uncrenulated) at the summit. The surrounding areolas are wide, extending almost to the upper and lower edges of the plate, thus leaving room only for a row of small granules between themselves and the border. Contiguous areolas are sometimes well separated by a broad miliary space ; more usually they are marked off only by a narrow line of granules and minute tubercles ; and in some places they are actually confluent.

The secondary tubercles differ from the primary ones only in size and in their proportionately smaller boss.

According as the space between the primary tubercles is greater or less, so we have usually secondary tubercles, minute tubercles, or only granules upon it. The tubercles of the ambulacral and interambulacral areas are in no way themselves distinguishable ; and those upon the scale-plates of the mouth-area differ from them only in size.

The two orders of spines are seen strewed over the whole test. The primary ones (fig. 8) are small and slender, and, with the pocket-lens, are seen to be longitudinally sulcated. The head is long and slightly swollen, with a faint ring surrounding the glenoid cavity; its collar is prominent and crenulated by broad and deep incisions, which, gradually narrowing along the steep neck, become continuous with the sulcations of the stem. This stem is very uniform, tapering but slightly, and it is hollow.

The secondary spines vary from $\frac{1}{8}$ inch to about $\frac{1}{2}$ inch in length. They are slender, taper very slightly, and end in a blunt point. Their articular end is much less conspicuous than in the primary spines. Other spines intermediate between these two were supported by the secondary tubercles.

Measurements.

	millim.
Diameter of test	100
,, ,, actinal area	34
Breadth of interambulacral area at oral extremity	13
,, ,, ,, ,, equator	44
,, ,, ,, plate at oral extremity	6
Height of interambulacral plate at oral extremity	2
Breadth of interambulacral plate at equator	23

	millim.
Height of interambulacral plate at equator	$4\frac{1}{2}$
Breadth of ambulacral area at equator	16
" " " oral pole..........	10
" large ambulacral plate at equator......	4
" small ambulacral plate at equator	2
" poriferous zones.....................	$4\frac{1}{2}$
Length of buccal plate	8
Breadth of buccal plate	4
" exposed part of buccal plate	1
Length of secondary spines ......from 3 millim. to	10
" primary spines ....nearly	20

II. Dr. Wright's Specimen.

Like the one just described, this specimen has only the oral aspect exposed, and of this hemisphere about two thirds are well preserved. The jaws are conspicuous, the large and powerful "alveoli" (measuring 25 millims. by 10 millims.) being in strong contrast with the delicate nature of the test.

Only a few of the overlapping plates of the buccal area are scattered about, and these, together with the ambulacral and interambulacral areas of the test, all agree precisely with the more perfect specimen already described above.

Some overturned interambulacral plates show that every primary tubercle is represented in considerable detail by a pit on the internal surface of the plate, even the ligament cavity of the tubercle having a corresponding prominence in the internal pit.

The primary spines (fig. 8) are numerous and larger than those preserved in the Cambridge specimen. They measure 23 millims. The broken ends of these spines show that they were hollow, the cavity being usually filled with a crystalline carbonate of lime, darker in colour than the spine substance.

But the most remarkable feature of this Urchin is shown on a part of the surface near the mouth where the coronal plates have been removed. Here, instead of the bare oolite rock, we see exposed a series of thin imbricating scale-like plates (fig. 10), which appear to have been internal to the ordinary coronal plates. They are very irregular, both in size and shape, two contiguous ones in one place being equal and similar to each other; but in another pair one plate is half as large again as the other. Still, in their general size and proportions, they are similar to the overlying interambulacral plates. Their contours are all rounded or gently undulating, and their surface is simple and marked only by a minute punctation. Their thinness is extreme.

It is not easy to determine what was the natural relation of this set of plates to the rest of the test. They are certainly not internal views of ordinary interambulacral plates, for they are too irregular, they overlap each other, and, moreover, do not exhibit any depression to correspond with the primary tubercles. One is first reminded by them of the actinal system of overlapping plates; but these latter are not so large, and are less regular in thickness; especially, too, the proportions of the exposed to the overlapped portions in the two forms of plates do not at all agree*. It may be that they formed an extra internal supporting skeleton to this fragile test, the buccal membrane having developed inwardly to extend up over that part of the test nearest to the mouth and secreting these calcareous plates. But additional evidence must be obtained from other specimens before this can be proved.

Some groups of irregularly perforated plates underlying part of the ambulacral zone are probably parts of the internal surface of the same zone crushed in from the apical side.

Pelanechinus, nov. gen.

Generic characters.—Test thin, in form circular, depressed. Composed of (1) transversely elongated coronal plates, (2) apical plates surrounding the anus, and (3) an actinal system of imbricating plates around the mouth. *Interambulacral areas* narrow at the poles, but rapidly broadening towards the ambitus, and bearing numerous (six to eight) rows of primary tubercles. Interambulacral plates narrow, their contours rounded and slightly undulating.

Ambulacral areas one third as broad as the interambulacral (at the equator), supporting two ranges of primary tubercles. *Poriferous zones* broad, the pores trigeminal in the equatorial region.

Primary tubercles rather small, perforated, and mounted upon elevated bosses with smooth uncrenulated summits; they are uniform over both areas.

Peristome deeply notched. Actinal area extensive (about three eighths of the whole test), covered with zones of large imbricating scale-like plates, which are perforated for the tube-feet and bear perforated tubercles.

Spines small, hollow. *Jaws* large and powerful.

The above characteristics will readily serve to distinguish *Pelanechinus* from all other fossil genera yet known. None at all resemble it in the nature of its actinal system of plates, except the *Echinothuria* of the Chalk; and from this genus it differs widely. We shall find, however, a much closer relationship between *Pelanechinus* and the deep-sea *Asthenosoma* (*Calveria*). Their general similarity of appearance is striking, and these are the only two genera of Urchins yet described as having a diademoid test associated with overlapping buccal plates. Both are further characterized by their very thin and narrow plates, their strong jaws, and hollow spines.

Asthenosoma is well distinguished from our genus by its imper-

* Only about one fifth of each plate is overlapped in the set we are now considering, whilst about two thirds of the actinal plates are so covered.

fectly calcified test, and its free pore-plates; but I would link them close in classification. It is this resemblance to a notoriously flexible Urchin which confirms my impression of the pliability of *Pelanechinus*—an impression at once suggested by the general appearance of the Cambridge specimen, which, although compressed, is not fractured, but has an undulating surface as though it had of itself collapsed. Commonly, when an Echinus is crushed its brittle plates are fractured across; but in this not a single plate is broken. Again, the extreme thinness of the plates themselves induces the belief that *Pelanechinus* was an exception to the rule of rigidity in the Sea-urchins.

Amongst the Cidaridæ, *Dorocidaris papillata* *, and *Cidaris coronata* as described by Quenstedt †, present the same essential features in their mouth-membrane plates; but their coronal characters are very different from those of *Pelanechinus*.

Although this Sea-urchin was referred to the genus *Hemipedina* by Dr. Wright, these latter specimens have shown that there is no real affinity with that genus; and, moreover, its test is distinguished from all species of *Hemipedina* by the trigeminal-pore arrangement ‡.

The extreme narrowness of the plates will be useful in distinguishing fragments from *Pedinæ* and *Hemipedinæ*.

Professor A. Agassiz has, in his 'Revision of the Echini,' already pointed out the similarity of the imbricating mouth-plates of *Asthenosoma* to the whole test in several genera of our most ancient (Palæozoic) Echini; and he also suggests that the coronal system of the latter may have been altogether suppressed. In this inquiry *Pelanechinus* is likely to prove very instructive when more specimens are obtained, such as will settle the nature of the thin irregular plates described *suprà*, p. 927.

It must not, however, be supposed that there is any near relationship between these modern Echinothuridæ and the ancient Perischoechinidæ. They are well separated by important and fundamental structural differences, and they form two separate branches distinct from their origin. The elder group is probably the highway from the Cystids to the Echinoids, &c. The Echinothuridæ are a branch from the latter.

Pelanechinus is a link between the ordinary Diademoid and the more exaggerated *Echinothuria* and *Asthenosoma*.

Only this one species of *Pelanechinus* is yet known (viz. *P. corallinus*, Wright, sp.); but there are other oolitic Diademoid Urchins, such as *Hemipedina marchamensis*, Wright, which may prove to belong to our new genus. Especially, too, I would notice a Chalk species of *Diadema* with thin and narrow plates and hollow spines, of which I have seen some fragments.

* A. Agassiz, 'Revision of the Echini,' t. ii. *b*. f. 2 & 3.

† Quenstedt, 'Petrefactenkunde Deutschlands,' t. lxii. f. 100.

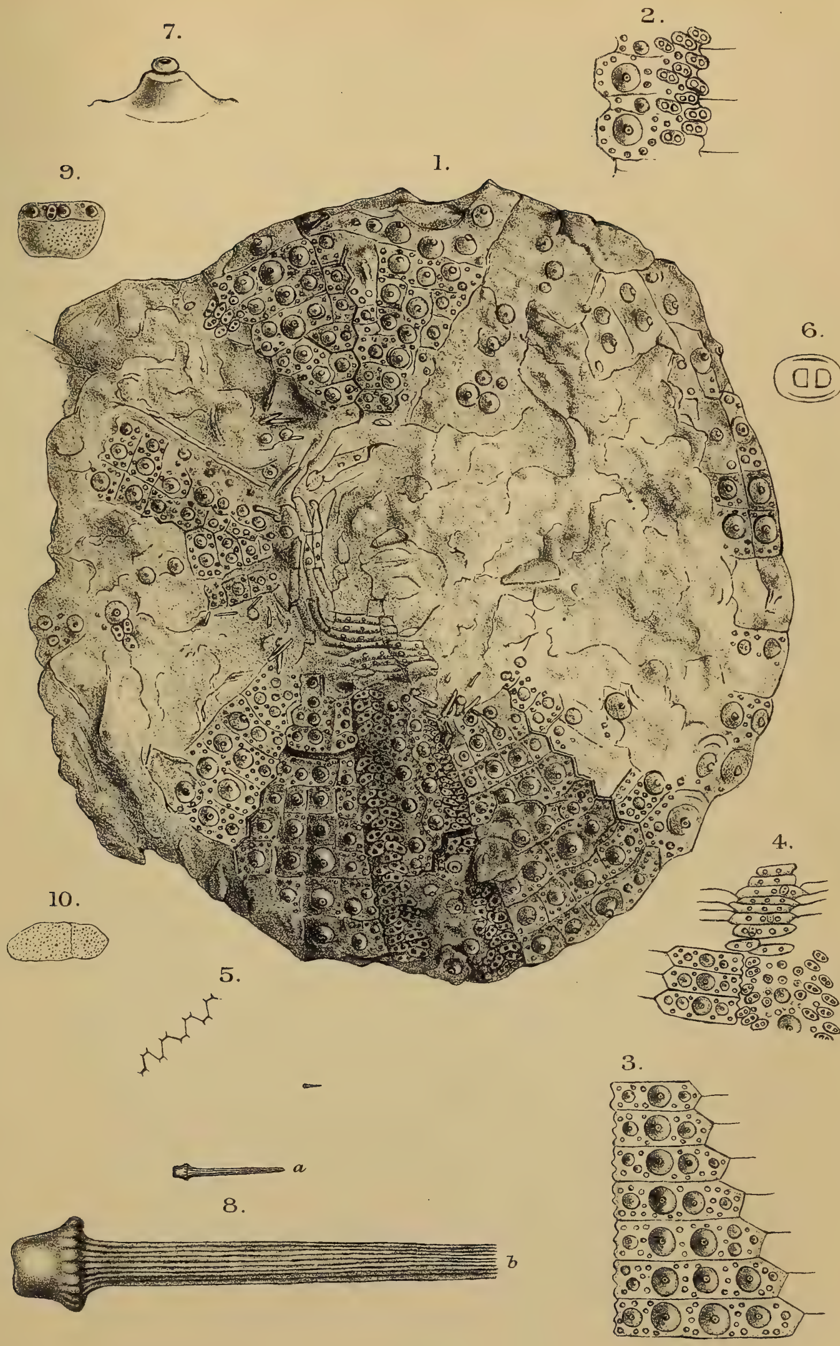
‡ It is true that *H. Tomesii* has trigeminal pores; but these groups of pores are abnormally directed upwards and outwards, whilst *Pelanechinus* has the usual arrangement in its trigeminal series.

EXPLANATION OF PLATE XXXIV.

Pelanechinus corallinus, Wright, sp.

Fig. 1. *Pelanechinus corallinus*, Wr., sp.
2. Ambulacral area.
3. Interambulacral area.
4. Portion of the corona near the mouth-opening, with the overlapping buccal plates.
5. Plan of the median ambulacral suture.
6. An ambulacral pair of pores, enlarged.
7. Outline of the side view of a tubercle, enlarged.
8. Spine: *a*, natural size; *b*, magnified three times.
9. Plate from the actinal (buccal) area.
10. Internal (?) plate.

Figs. 1–7 are from a specimen in the Woodwardian Museum, Cambridge; figs. 8–10 are from the one in Dr. Wright's cabinet. All the figures are natural size, except where otherwise stated.



A. S. Foord. lith.

Mintern. Bros imp.

PELANECHINUS.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

[The fossils referred to are described; and those of which the names are printed in italics are also figured.]

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