Vol. XXXI

THE

QUARTERLY JOURNAL

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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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.]

Printed by Taylor and Francis, Red Lion Court, Flee Street.

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SYLLABUS OF LECTURES ON MINERALOGY,

ADAPTED TO FACILITATE THE STUDY OF GEOLOGY AND OF MINERAL SUBSTANCES USED IN THE ARTS,

Which will be given by J. TENNANT, F.G.S., Professor of Geological Mineralogy at King's College, London, on WEDNESDAY and FRIDAY Mornings from 9 to 10, and on THURSDAY Evenings from 8 to 9.

The Course will commence with a description of the Physical and Chemical Characters of Minerals in general.

PHYSICAL CHARACTERS.—Crystallization, Cleavage, Fracture, Frangibility, Hardness, Lustre, Colour, Flexibility, Double Refraction, Touch, Taste, Odour, Streak, Powder, Adhesion to the Tongue, Magnetic and Electric Properties, Phosphorescence, Specific Gravity.

CHEMICAL CHARACTERS.—Use of the Blowpipe, Action of Acids, etc.

The principal simple Minerals will be next separately considered, and the readiest mode of distinguishing them described. The following is the order adopted:—

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B. *Combustible Minerals.*—Sulphur, Bitumen, Coal, Jet, Amber, etc.

C. *Minerals used in Jewelry.*—Diamond; Coloured varieties of Corundum—Sapphire, Ruby, Topaz—called Oriental Stones: Spinel, Turquoise, Topaz, Emerald, Beryl, Hyacinth, Tourmaline, Lapis-lazuli, etc.

D. The *Metalliferous Minerals* will be fully described in the Practical Course.

The Course of Instruction will include a minute description of all the substances entering into the composition of Rocks, and of those Minerals which are also used in the Arts, illustrated by an extensive collection of characteristic specimens and diagrams of the principal crystalline forms, etc.

The above Lectures commence in October and end at Christmas.

To be followed by Lectures on Rocks and Metallic Minerals.

The Lectures delivered on the subject of Geological Mineralogy are intended to have especial reference to the important practical applications of that science to Engineering, Mining, Architecture, and Agriculture. The Granites, Syenites, Porphyries, Greenstones, Clays, etc., will be described, and the Minerals peculiar to each noticed.

The application of Geology to pursuits connected with Mining-operations for Coal, Iron, Copper, Tin, Silver, Gold, Mercury, Antimony, Zinc, Cobalt, etc., will be specially considered. The Student is directed how to proceed in the examination of a new country, how to collect and record his observations, and to mark his specimens, in order to render them useful to more experienced geologists at home.

In order more fully to exemplify the applications of the Science, Mr. Tennant accompanies his Classes to various Museums in London, including the Museum of Practical Geology and the British Museum; also on excursions into the country, in which the actual field-work of the Geologist is explained and illustrated.

The above Lectures commence in January and end at Easter.

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PRIMARY, OR PALÆOZOIC SERIES.—Permian, Carboniferous, Devonian, Silurian, and Cambrian Groups.

The mode of Collecting, Cleaning, and Arranging Fossils, Minerals, and Rock-specimens will be described.

PRIVATE INSTRUCTION on the above subjects is also given at 149, STRAND, W.C., by Professor TENNANT.

[*Extracted from the* GEOLOGICAL MAGAZINE, Decade II., Vol. II., No. 11, November, 1875.]

NOTES ON DIAMONDS FROM THE CAPE OF GOOD HOPE.[1]

By Professor TENNANT, F.G.S.

THE first South African diamond was found in March, 1867, and on examining its physical characters, it was pronounced by Dr. Atherstone to be genuine. When this stone was received in London, it created considerable interest, and also some degree of suspicion, some persons having asserted that it was brought forward for mercenary purposes; letters even appeared in the public papers implying that it was impossible it could have been found near Hope Town. As Dr. W. G. Atherstone, F.G.S., of Graham's Town (who in March, 1867, examined and pronounced the stone to be a diamond), is now in Bristol, I beg to offer a few general remarks on the Cape diamonds, and also to express in public my thanks to him.

The late Mr. Mawe, who wrote on diamonds, and described their mode of occurrence in his Travels in Brazil (London, 1812), often expressed to me his opinion of the probability of their existence in South Africa, and said that if people only knew them in the natural state he felt confident they would be found.[2] He died in 1829, and I took every opportunity to make the subject known by means of short papers, accompanied by figures showing the ordinary crystalline form of the diamond.

The number and quality of diamonds from the Cape are equal to those from the Brazils, which have chiefly supplied Europe during the last eighty years.

About ten per cent. of the Cape diamonds may be classified as of the first quality, fifteen per cent. of the second, twenty per cent. of the third; the remainder, under the name of *bort*, are employed for cutting diamonds, and for the various economic purposes to which this valuable substance is applied by the glazier, the engineer for drilling rocks, the lapidary, and others. Many diamonds contain specs and cavities; these are placed in the hands of skilled workmen who are acquainted with the cleavage, and by careful manipulation they are frequently able to remove these blemishes, and so to obtain portions of the gems of the first quality for making small "brilliants," "roses," and "tables."

The cutting and polishing of diamonds was carried on in London with great success 200 years ago; subsequently it was carried on chiefly in Holland; but several attempts have been made to re-establish the trade in this country.

In 1874 the Turners' Company offered prizes, in the form of medals and the freedom of the City of London, for the best specimens

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[1] Read before the Geological Section of the British Association at Bristol, September 1st, 1875.

[2] Prof. Tennant explained that the diamond in its natural state bore considerable resemblance to a piece of gum.

of diamond-cutting. The Baroness Burdett-Coutts has supplemented this by the addition of money prizes, and has offered to contribute the further sum of £50 for prizes in the year 1876.

It is estimated that the value of the diamonds found at the Cape from March, 1867, to the present time, exceeds twelve millions of pounds sterling.

I am enabled to exhibit not only a large collection of these diamonds, but also samples of the natural materials found associated with them.[1] In November, 1873, one of my former students brought me the specimen from South Africa represented in Fig. 1, which in its original state weighed 112 carats; it has since been cut by a London firm of diamond-cutters into the beautiful brilliant represented by Figs 2, 3, and 4, weighing 66 carats. The stone has a delicate yellow tinge, and exceeds *in size and brilliancy any diamond in the British Crown.*

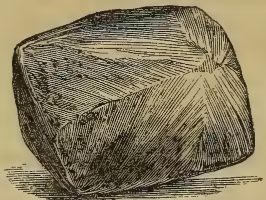

Fig. 1.

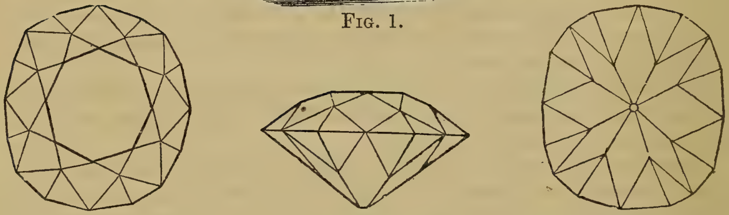

Fig. 2, Front View. Fig. 3, Side View. Fig. 4, Back View.

Fig. 1.—Natural Crystal of a Diamond recently found in South Africa.

Figs. 2–4.—Three views of the same stone after having been cut as a brilliant by a London diamond-cutter.

It may be remarked, with regard to this class of gem-cutting, that 200 years since the English diamond-cutters were the most celebrated in the world. The diamond-cutting trade is now coming back to England, and the stone figured above affords a fair sample of what excellent work can now be done here. I may mention that the stone in its present form is worth £10,000, whilst the value of the models of it, which have been cut by the best lapidaries, is a mere trifle, that in glass costing but 10s., and that in crystal but £2. The rule given by Jeffries and the best authorities upon diamonds for ascertaining the value of cut diamonds, is to multiply the square of the weight in carats by eight, and call it pounds, so that this diamond would, according to this computation, be worth 66 × 66 × 8 = £34,848.

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[1] Prof. Tennant exhibited a South African diamond in the matrix (consisting chiefly of broken fragments of chloritic and clay-slates), likewise some interesting photographs of the Diamond-workings in South Africa.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1874–75.

November 4, 1874.

John Evans, Esq., V.P.R.S., President, in the Chair.

Henry Michell Whitley, Civil Engineer, Assoc.Inst.C.E., Secretary for London of the Royal Institution of Cornwall, 4 Great Queen Street, Westminster, and Horatio Brothers, Esq., M.Inst. C.E., Engineer to the Western Division of the Chartered Gas-light and Coke Company, 1 Bessborough Street, S.W., were elected Fellows of the Society.

The List of Donations to the Library was read.

Specimens of Livingstonite, a new mineral (sulphide of antimony and mercury) from Huitzuco, Mexico; presented by its describer, Don Mariano Barcena.

Specimens of Bauxite from Les Baux, Bouches du Rhône; presented by John Evans, Esq., V.P.R.S., Pres. G.S.

The following communication was read:—

"Notes on the Comparative Microscopic Rock-structure of some Ancient and Modern Volcanic Rocks." By J. Clifton Ward, Esq., F.G.S.

November 18, 1874.

John Evans, Esq., V.P.R.S., President, in the Chair.

George Harry Piper, Esq., Solicitor, of Court House, Ledbury; John Peter, Esq., of Ivy House, Bala; and C. J. Homer, Esq., of Chatterley Hall, Tunstall, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On Fossil Evidences of a Sirenian Mammal (*Eotherium ægyptiacum*, Ow.) from the Nummulitic Eocene of the Mokattam Cliffs, near Cairo." By Prof. Owen, F.R.S., F.G.S., &c.

2. "On the Geology of North-west Lincolnshire." By the Rev. J. E. Cross, M.A., F.G.S.

The following specimens were exhibited:—

Cast of the brain and fragments of the skull of *Eotherium ægyptiacum*; exhibited by Prof. Owen, in illustration of his paper.

Oolitic and Liassic Fossils from Lincolnshire; exhibited by the Rev. J. E. Cross, in illustration of his paper.

Fragments of Jaws of *Elephas primigenius* from Crayford; exhibited by Prof. Tennant, F.G.S.

December 2, 1874.

John Evans, Esq., V.P.R.S., President, in the Chair.

Señor Carlos Alfonso Gonzalez y Orbegoso, of Lima and Truxillo, Peru; George F. Playne, Esq., of Whitecroft, Nailsworth, Gloucestershire; Thomas Cotton, Esq., M.D., 214 Seven Sisters' Road, Holloway, N.; Henry Mere Ormerod, Esq., Clarence Street, Manchester; Samuel Herbert Cox, Esq., F.C.S., of the Geological Survey of New Zealand; the Rev. Henry Mahony Davey, M.A., Portfield Vicarage, near Chichester; William Nicholas, Esq., of the Scientific Branch of the Mining Department of Victoria, Melbourne; Henry Wilson, Esq., Marske-by-the-Sea, Yorkshire; James Paterson, Esq., Warrington; Arthur Henry Stokes, Esq., one of H.M. Inspectors of Mines, Derby; Arthur Dudley Dobson, Esq., C.E., Nelson, New Zealand; G. F. Adams, Esq., C.E., Guildhall Chambers, Cardiff; Valentine Ball, Esq., M.A., Geological Survey of India, Hastings Street, Calcutta; C. L. Griesbach, Esq., 64 Elgin Crescent, W.; Alexander Grant, Esq., M.A., of Mayleigh, Petersham, Surrey; and George J. Hinde, Esq., of Yorkville, near Toronto, Canada West, were elected Fellows of the Society.

The List of Donations to the Library was read.

Fossils from the Oolitic and Liassic deposits of North-west Lincolnshire were presented by the Rev. J. E. Cross, F.G.S.

The following communications were read:—

1. "On the Femur of *Cryptosaurus eumerus* (Seeley), a Dinosaur from the Oxford Clay of Great Gransden." By Harry Govier Seeley, Esq., F.L.S., F.G.S., Professor of Physical Geography in the Bedford College, London.

2. "On the Succession of the Ancient Rocks in the vicinity of St. David's, Pembrokeshire, with special reference to those of the Arenig and Llandeilo groups and their fossil contents." By Henry Hicks, F.G.S.

The following specimens were exhibited:—

Fossils from the Arenig and Llandeilo rocks of St. David's; exhibited by Mr. Hicks.

Graptolites from the Arenig and Llandeilo rocks of St. David's; exhibited by Mr. Hopkinson.

December 16, 1874.

John Evans, Esq., V.P.R.S., President, in the Chair.

Thomas Warburton, Esq., 11 Grange Road, Canonbury Park, N.; William Watts, Esq., of Piethorne, Rochdale; J. G. Grenfell, Esq., B.A., of Clifton College, Bristol; Thomas Karr Callard, Esq., 4 Blenheim Terrace, St. John's Wood, N.W.; Jeremiah Slade, Esq., 100 Barnsbury Road, N.; Henry Stopes, Esq., East Hill, Colchester; John Gibson, Esq., M.A., Albert College, Belleville, Ontario, Canada; Ramsay Heatley Traquair, Esq., M.D., Keeper of the Natural-History Collections in the Edinburgh Museum of Science and Art, 28 Upper Gray Street, Newington, Edinburgh; and Robert O. Cunningham, Esq., M.D., F.L.S., Professor of Natural History, Queen's College, Belfast, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "Descriptions of the Graptolites of the Arenig and Llandeilo Rocks of St. David's." By John Hopkinson, Esq., F.G.S., and Charles Lapworth, Esq., F.G.S.

2. "On the Age and Correlations of the Plant-bearing series of India, and the former existence of an Indo-Oceanic Continent." By H. F. Blanford, Esq., F.G.S.

January 13, 1875.

John Evans, Esq., V.P.R.S., President, in the Chair.

George Guillaume André, Esq., Civil and Mining Engineer, 16 Craven Street, Strand, W.C.; Alexander Brogden, Esq., 51 Prince's Gate, W.; Alfred Eugene Craven, Esq., Kenwood Bank, Sharrow, Sheffield; George Welland Mackenzie, Esq., F.R.C.S., L.R.C.P., 15 Hans Place, S.W.; Major Thomas Benton Brooks, of the Geological Survey of Michigan and Wisconsin, Marquette, Lake Superior; Conway Lloyd Morgan, Esq., Assoc. R.S.M., Weybridge Heath, Surrey; Walter Flight, Esq., D.Sc.Lond., of the Mineral Department of the British Museum, 51 Lincoln's Inn Fields, W.C.; Douglas H. Gordon, Esq., of the Geological Department of the British Museum, 6 Chichester Road, Westbourne Square, W.; Arthur White, Esq., The Cedars, Hammersmith Road, W.; and Charles Callaway, Esq., M.A., B.Sc., Curator of the Sheffield Town Museum, 283 Glossop Road, Sheffield, were elected Fellows; and M. Paul Gervais, of Montpellier, and Prof. F. Sandberger, of Würzburg, Foreign Members of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Kimmeridge Clay of England." By the Rev. J. F. Blake, M.A., F.G.S.

2. "Note on *Pelobatochelys Blakei* and other Vertebrate Fossils obtained by the Rev. J. F. Blake from the Kimmeridge Clay." By Harry Govier Seeley, Esq., F.L.S., F.G.S., Professor of Physical Geography in the Bedford College, London.

3. "On the Cambridge Gault and Greensand." By A. J. Jukes-Browne, Esq., F.G.S.

The following specimens were exhibited:—

Fossils from the Kimmeridge Clay; exhibited by the Rev. J. F. Blake, in illustration of his paper.

Fossils from the Cambridge Gault and Greensand; exhibited by Mr. Jukes-Browne, in illustration of his paper.

Specimens of *Ammonites tatricus*, Pusch, from the Oxford Clay of St. Ives, new to Britain; exhibited by Mr. J. F. Walker, F.G.S.

January 27, 1875.

John Evans, Esq., V.P.R.S., President, in the Chair.

Alexander Heatherington, Esq., of Halifax, Nova Scotia; John Cliff, Esq., Runcorn; Henry Wagner, Esq., M.A., of the Inner Temple; Franklin Gillespie, M.D., Royal Military College, Sandhurst; Richard Nicholls Worth, Esq., 3 Patna Place, Plymouth; John Cowlishaw, Esq., Chapeltown, near Sheffield; Frederick Warwick, Esq., 25 Bucklersbury, E.C.; Robert Darell Smythe Stephens, Esq., St. Stephens, Plympton, Devonshire; Charles Smith, Esq., of Crosslands, Dalton-in-Furness; and Francis Oats, Esq., Government Mining Engineer, at the Diamond Fields, Griqualand West, South Africa, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Structure and Age of Arthur's Seat, Edinburgh." By John W. Judd, Esq., F.G.S.

2. "The Glaciation of the Southern part of the Lake-District, and the Glacial Origin of the Lake-basins of Cumberland and Westmoreland."—Second Paper. By J. Clifton Ward, Esq., F.G.S.

The following specimens were exhibited:—

Diamonds and other minerals; exhibited by Prof. Tennant, F.G.S.

Photographs of the South-African Diamond-fields; exhibited by Prof. Tennant, F.G.S., on behalf of Mr. Ford.

Six specimens of Slate, showing "faulting;" exhibited by Mr. C. E. De Rance, F.G.S.

THE

QUARTERLY JOURNAL

OF

THE GEOLOGICAL SOCIETY OF LONDON.

VOL. XXXI.

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1. GEOLOGICAL NOTES *on the* SINAITIC PENINSULA *and* NORTH-WESTERN ARABIA. By JOHN MILNE, Esq., F.G.S. (Read June 24, 1874.)

THE journey of which the following is an account, was made in company with the late Dr. Beke in quest of the true Mount Sinai, which mountain he placed in North-western Arabia, about 95 miles in a north-easterly direction from the district in which it has hitherto been conjecturally considered to exist.

Owing to the rapidity with which the country visited was traversed, it would be impossible to connect with accuracy the various observations which were made; and therefore, rather than attempt to construct a series of sections showing the relation of the various formations to each other, I have considered it better simply to indicate the conditions as observed at various points, leaving it for those more conversant with the geology of these districts to connect the following fragments with those already accumulated. For assistance in the determination of the rock-specimens collected, of which 77 are described, 22 of which were examined microscopically, I have to thank Mr. Thomas Davies, F.G.S., of the British Museum.

District visited.—From Suez we went by sea to Eynounah, which lies in the north-east corner of the Red Sea, and then on to Akaba, touching almost daily at some point or other along the coast. From Akaba we took camels, and journeyed some twenty miles in a north-easterly direction up Wady Ithm, in the direction of Petra and Maan. This was the furthest point of our journey. On again reaching Akaba, instead of returning to Suez by sea, as we had come, we reached it by crossing the elevated desert plateau of the Tih.

Suez to Akaba.

Ras Sheik el Ballan.—This place is about 50 miles south from Suez, on the coast of the Sinaitic Peninsula. Here the hills, which are approached from the coast by about a mile of a gradually sloping sandy plain, are granitic. All the way from Suez the coast on either side is bounded by high and rugged hills, in general appearance very similar to these. Being destitute of vegetation, there has been no check to the effects of disintegration; and these mountains, which probably would have been more rounded in their outlines had they been protected by trees and herbage, now rise in bold and often almost perpendicular cliffs, contrasting strongly with the rounded granitic outlines seen in many parts of the British Isles, especially in Cornwall. Looking at these hills from a distance, they appeared as if built up of so many triangular slabs which had been laid over the surface of some preexisting hill. The tops or apices of these slabs pointing upwards give rise to innumerable peaks, forming prominent serrations on the ridge and rough points upon the sides. The granite is of a greyish colour, and consists chiefly of quartz and a black mica, little felspar being present. These mountains are cut by numberless dykes, which are generally nearly vertical, but yet often intersect each other at small angles. Looking at these from the coast, they appear as so many well-defined broad red or dark-coloured bands. At this place, Ras Sheik el Ballan, the red bands were felsites, whilst those of a dark colour, which varied from a black to olive-green, were felspathic porphyries. The two might easily be distinguished by blows of the hammer—the former being hard and compact, and having a clear metallic ring when struck; whilst the latter, being much decomposed, sounded dull, and readily crumbled. In places some of these dykes were filled with small cavities containing a white glassy mineral, which in several cases, having dissolved out, gave to the rock a vesicular structure.

In width these dykes vary considerably; those examined varied from 6 to 12 feet.

Lying on the sand about a quarter of a mile from the foot of the mountains, there are some curious slabs of sandstone from three to six feet square, made up of readily separable laminæ of $\frac{1}{4}$ to $\frac{1}{8}$ inch in thickness. These slabs are hard, brittle, slightly calcareous, of a gritty siliceous structure and nearly white. They probably come from beds of the so called Libyan Sandstone, of which there is an exposure somewhere near this place.

Dr. Beke tells me that when travelling from Tor towards Suez along this coast he passed over a surface of fine sandstone like the one just described, on which there were numerous tracks of birds' feet apparently as fresh and perfect as if only just impressed.

Here the curious forms assumed by drifted sand could be well observed. When sailing along the coast, from high up between sloping walls of granite bounding the valleys, the sand can be seen descending like a glacier. Every gorge and valley is filled from side to side with it; and from high up, at a narrow terminus where the sides of granite approach each other, there is a sloping even surface which comes winding down until it merges in the plain below.

As at this point there was no valley, the glacier-like form did not exist, but in its place were long winding sandy ridges running from the foot of the hills and terminating abruptly in the plain some 50 or 100 yards from their origin. A section at right angles to the length of one of these, would give two sides sloping upwards at about 45°, meeting at an angle some 12 or 14 feet above the ground. Running up these two faces there are parallel lines very similar to regularly formed ripple-marks, which give the surface a corrugated appearance. The curious point, however, is that the ripple-marks on one side of the mound alternate with those on the other; that is to say, where the crest of one ripple-mark running up the side of the mound reaches its ridge, there it meets with the hollow of a ripple-mark on the opposite side, in this way causing the ridge to be a regularly formed waved line.

Similar structures to these mounds of sand I have seen in Iceland built up of ashes, but on a much larger scale. Those on the north-east side of Godalands Jokull, are ridges half a mile in length running from the top of the hills down to the valley below, and have a striking resemblance to some huge railway embankment.

Tor.—A short distance before reaching this place the high range of granitic hills which borders the coast gradually grows lower, and finally disappears in the sand. Many of the dykes in them are approximately parallel, and those which are not vertical dip towards the south. As this range of hills, which from the map appears to be called Jebel Gabêliyeh, dies out, another range rises in the rear, which as it proceeds southwards approaches the sea-board, from which at first it is some 15 or 16 miles distant. The highest of these, Jebel Serbal, 6734 feet, has, amongst others, a claim to be the true Mount Sinai. Between it and the sea where Tor is situated there is a broad and gently undulating plain. Tor itself, although a small village, has a striking feature in being built almost wholly of blocks of coral obtained from some large mounds about 100 yards to the north, which, when they come down to the shore, form small cliffs from 20 to 30 feet in height. These mounds, which are made up of sand, imbedded masses of coral, and a variety of shells, are apparently a drift accumulation—an idea suggested by the imperfect condition of the shells and the irregular manner in which they appear to be thrown together.

Sherm.—At page 396 of Mr. Poulett Scrope's work on volcanoes it is stated, on the authority of Burckhardt, that there is a probability of the existence of volcanic rocks at Sherm. Burckhardt, when speaking of this district in his 'Syria' (page 522), says, "the transition-rock, which partakes of the nature of greenstone or grauwacke or hornstone and trap, presents an endless variety in every part of the peninsula; so that, even were I possessed of the requisite knowledge, to describe them accurately would try the patience of the reader. Masses of black trap much resembling basalt compose several isolated peaks and rocks;" and at page 529, he continues, "from Sherm we rode an hour and a quarter among low hills near the shore" [towards Akaba]. "Here for the first and only time I saw volcanic rocks. For a distance of about two miles the hills presented perpendicular cliffs, formed in half-circles, and some of them nearly in circles, none of them being more than from 60 to 80 feet in height; in other places there were appearances as of volcanic craters. The rock is black, with a slight reddish tinge, full of cavities, and has a rough surface; on the road lay a few stones which had separated themselves from above. The cliffs were covered by deep layers of sand; and the valleys at their foot were also overspread with it. It is possible that rocks of the same kind may be found towards Ras Abou Mohammed; and hence may have arisen the term black (μέλανα ὄρη), applied to the mountains by the Greeks. It should be observed that low sand hills intervene between the volcanic rocks and the sea, and that above these, towards the higher mountains, no traces of lava are found, which seems to show that the volcanic matter is confined to this spot."

Of these remains of an extinct volcano or volcanoes the only trace obtained was the picking-up of a few pieces of volcanic breccia, as will be seen from my notes on the neighbourhood, which unfortunately, from want of time, relate only to the harbour.

From this place to Ras Abou Mohammed, the most southern point of the Sinaitic Peninsula, there is an absence of the granitic rocks, which keep some 6 or 7 miles back from the coast-line, their place being supplied by low hills and cliffs of limestone and sandstone. On the east side of Sherm harbour, the cliffs, which are about 50 feet in height, are formed of sand, capped with two horizontal beds of yellowish white limestone. These latter, which are about 14 feet thick, are full of irregular cavities, and are in fact rather a breccia of shells and coral than a compact limestone.

The beds of sand, which in places appear to dip at about 12° towards the south, although compact, are much too friable to be called a sandstone. They are of a yellowish red colour, and in places are formed of quartz grains as large as peas, giving the character of a *grit*. Intercalated with them is a band about 6 inches wide, of rounded and angular pieces of flint, quartz, and granite. Masses of limestone, having fallen from the beds above, form a protection against disintegrating forces, which rapidly tend to undermine them. Passing from these cliffs round the harbour in a northerly direction, across the entrance to a wady running to the north-east, steep banks of sand are met with, which continue to its south-west side. These are generally of a yellowish colour; but in one or two places they were of a fiery red. At several points there are indications which might be taken for horizontal bands of a black colour, forming a cap to these banks of sand; where these do not exist their remains are seen in taluses of black *débris*.

Want of time prevented a close examination of these; but judging from the numerous fragments of black stone lying on the beach, it would appear that they were in part, if not wholly, of volcanic origin. Generally speaking, they were compact, fine-grained, of a black colour, and even in their texture. Under the microscope, however, they were distinctly seen to be a volcanic felspathic breccia (probably doleritic particles cemented by a triclinic felspar)—a condition which, from external appearances, would never have been suspected, unless from a slight irregularity on the weathered surfaces of the specimens. With them were a few fragments of a coarse-grained black rock, consisting of quartz and felspar cemented by limonite, which is distinctly a breccia.

To the west, behind these banks of sand, low hills with rounded outlines run from north to south, which have a definite stratification and dip towards the north.

The cliffs of Ras Abou Mohammed, lying to the south-west, are about 90 feet in height, and are apparently composed of the same coral limestone as that forming a cap to the sand at Sherm, with which they also agree in the direction of their dip.

Inland from the cape there is a curious round hummock-shaped black hill.

From Sherm our course was close along the shore of the Sinaitic Peninsula, along which nothing but rugged hills of granite and "dunes" of sand were visible.

At the entrance to the Gulf of Akaba we sailed due east to Eynounah, the approach to which was for many miles guarded by innumerable coral reefs, on which the soundings were seldom over 2 fathoms. At Eynounah, excepting a few palm trees and the remains of an aqueduct apparently of Roman origin, there is but little of interest. The hills, which are very high, several of them being upwards of 7000 feet, are a day's journey or more distant from the coast. About halfway towards them there is a long low white scarp, forming the flank of a range of hills or a low plateau, which is probably limestone. The remainder of the country is flat, and slightly undulating, being for the most part covered with stones and sand; notwithstanding which, relatively speaking, it is very fertile, many bushes, acacias, and small date-palms being visible.

Between this place and the entrance to the Gulf of Akaba there are many islands, all of which, judging from their similarity in appearance to those examined, are made up of a whitish limestone dipping at a low angle towards the east.

Madian.—The first place landed at inside the Gulf of Akaba was Madian, up to which point both sides of the gulf are bounded by bleak and bare high hills of granite. Here there is a Bedouin village, situated on the sea-board at the termination of a valley or wady coming down from the east. This valley at its mouth forms a boundary line between two sets of lithologically different rocks.

On the right or south side is a granite, whilst on the left or north side there are beds of sandstone and conglomerate.

The granite, which is more or less of a reddish colour, is in such a decomposed state on its surface, that at a short distance it would be readily mistaken for a soft sandstone. Even in the more solid parts, when struck with a hammer it readily falls into angular pieces. Its texture varies considerably, being both fine and coarse; but in all parts the felspathic element predominates. The striking feature in this rock is the number of dykes by which it is traversed. These, generally speaking, have a strike from north to south, and a dip at a high angle of 80 or 85° towards the east.

In all the granite hills of these regions, there are visibly two classes of dykes, which are distinguishable from each other by their colour—black ones, which are generally dark-coloured coarse-grained porphyries, and red ones, which are for the most part pink felsites or fine-grained porphyries. Both of these are much disintegrated, but the former more so than the latter. On an east and west section about a quarter of a mile in length, out of eleven of the dark-coloured dykes, only two stood up to form peaks; the remaining nine, being softer than the granite, were cut down so as to form hollows and heaps of *débris.*

About half a mile up this valley, upon its south side, a bluff about 30 feet in height rises perpendicularly from the top of a large mound. This appears to show a junction of the granite and conglomerate; but the two externally appear to be so merged into each other that it is difficult to draw a marked line between them. The top of the bluff is covered with two horizontal bands of sand and rounded stones about six feet in thickness. On its southern side, beneath this cap there is a face of decomposing felspathic granite, traversed by greenish-coloured dykes, which include within themselves small angular fragments probably derived from some earlier-formed dyke which they have traversed. Passing round to the east side, there is an apparent gradation into red earthy bands, very like a hard clay, which in their turn merge on the north side into a brecciated conglomerate, which faces the sandstone beds on the opposite side of the valley. This conglomerate varies considerably in texture, containing not only pebbles, but also large boulders. Facing this bluff, upon the opposite side of the valley, which is here considerably narrowed, there is a corresponding bluff formed wholly of conglomerate. The upper part of this, which is made up of a coarse material, the stones it contains being as large as a cocoa-nut, lies unconformably upon a bed of finer material.

This lower bed in its upper portions is a gritty sandstone, but as it descends it passes into a fine conglomerate. Being much softer than the rock which caps it, it is rapidly being undermined, and large blocks of the coarse conglomerate from above are in consequence continually falling. These blocks, although they are made up of similar, if not the same, material as the neighbouring granite rocks, form, as far as their durability is concerned, a far superior stone—under the hammer the one giving a dull hollow earthy sound, and the other a clear sharp metallic ring.

Passing this bluff to the north side of the valley, we come on a gradually sloping plane of sandstone, grit, and conglomerate, the surface of which has been worn into a series of round hummock-shaped forms, each about 4 feet in height. Winding in and out between these there are smooth narrow channel-shaped hollows, looking as if at times they formed courses along which water had flowed; and, in fact, down one of these a small and rapid stream of water was descending, at the time of my visit, towards a palm-grove which occupies the bottom of the valley. In places where a cutting has been made from the valley into the hummocked plane of conglomerate and sandstone, the unconformability just spoken of is strikingly seen in several outliers, the tops of which are made up of conglomerate, which joins in an irregular line the sandstone of their lower portions.

About three quarters of a mile up the valley, on its north side there is an exposure, about 40 yards in length and from 20 to 30 feet in height, which exhibits a curious juxtaposition of sandstone, conglomerate, and breccia.

Not far from the place where this section is exhibited, and on the same side of the valley, there are the ruins of a temple called by the inhabitants the Mosque of Moses, which for the most part is built of large square blocks of a fine-grained and perfectly white alabaster. In the bed of the valley there were many large, tolerably angular blocks of this stone, which had evidently travelled down from the interior, where the inhabitants stated that at six hours' distance there was a mountain or a large hill wholly composed of this material, which, if like the samples seen, must be of an excellent quality for building-purposes.

A little further inland from this temple, where the valley forks, the sandstone crosses to the south side, and there exposes a section near 60 feet in height. On the top of this there are some 2 or 3 feet of the coarse conglomerate, which lie on sandstone beds dipping about 4° N.N.W. This sandstone is made up of some eighteen or twenty bands of a light yellow, fine-grained, quartzose material. Interstratified with these bands are ~~one~~ or two layers of an argillaceous shelly material, one of which contains several narrow veins of gypsum, each about half an inch in thickness, and, lower down the valley, also a decided quantity of common salt.

Rocks from Madian.

(All these, unless specially mentioned, were obtained from dykes traversing the granite. The first four were determined microscopically.)

1. Basalt, fine-grained, and of a greyish colour.
2. Diabase, fine-grained, even-textured, dense, and of a blackish green colour.
3. Diabase, only differs from No. 2 in being slightly greener and of a finer texture.

4. Diabase, slightly greener than Nos. 2 & 3.
5. Red Porphyry, compact, fine-grained, with hornblende.
6. Granite, highly felspathic, with but little mica, of a pinkish colour. A rock penetrated by dykes.
7. Granite similar to No. 6, but having small fissures containing dolomite.
8. Granite, similar to No. 6, but containing two felspars—one triclinic, and the other orthoclase.
9. Granite, greyish and much disintegrated, and thickly traversed by dykes.
10. Porphyry, a dark-coloured base thickly covered with small white crystals of felspar.
11. Porphyry, like No. 10, but with the felspar crystals long and acicular.
12. Dolerite, with brownish yellow olivine, of a vesicular structure, the cavities being in part filled with carbonate of lime. This was obtained from a boulder, of which there are many, all probably having their origin further up the wady to the east.
13. Degraded Basalt, like No. 1, both being found in small angular fragments in the interior of a dyke on the east side of the wady.

Madian to Omaider.—From Madian, continuing northwards along the east side of the Gulf of Akaba, the sandstone continued for some 4 or 5 miles, but in places apparently pierced by the granite, which at one time it probably covered, and towards the flanks of which it was now approaching.

On the west side of the gulf, although the hills were 15 miles distant, the dykes by which they were penetrated were distinctly visible.

As we neared the granite on the eastern side, the sandstone gradually sloped up towards it, or, in other words, dipped to the south or south-east, suggesting the idea just stated, that at one time it wholly buried these mountains which now raise themselves so high above it. When we were opposite what ought to have been the line of junction of the two, the stratification of the sandstone became so broken, and the outline of the decomposing granite so indefinite, that the relation of the two was not distinctly visible. The next object of geological interest was a flank of Jebel Tauran, which projected as a prominent bluff, the face of which formed a high and almost perpendicular cliff, through the centre of which was a cañon-looking gulch cleaving it from top to bottom. The height of this, if any reliance can be given to a rough calculation based on its altitude as taken by our captain, must have been over 2000 feet, which would almost put the crevasse-like opening on a par with a Western-American cañon.

Bir el Mashiyah.—A few miles to the north of this is the headland of Bir el Mashiyah, at which place another opportunity was given for visiting the shore. Here there is decided evidence that the land of this gulf and, probably in connexion with it, that of its neighbour the Gulf of Suez, are rapidly rising.

Running from the granite hills, which here recede some three or four miles from the shore-line, across a gently sloping plane which joins them with the sea, there are numerous regularly built mounds, like so many partially completed railway embankments, reaching from the mountains to within half a mile of the water's edge. These appear externally to be made up of materials derived from the hills from the foot of which they spring; but at several points a white rock can be seen cropping out, showing this detrital matter to be only a covering. This rock is a pure soft limestone of coarse texture, on the surface of nearly every square foot of which the section of a coral can be seen; but these, along with other fossils collected, remain yet to be described.

The only one of these mounds which I had an opportunity of examining was about 90 feet in height, and showed an exposure of about 30 feet of this limestone, as measured from its base, which is about 10 feet above sea-level. From this it would appear that there must have been an elevation of at least 40 feet.

From this place up to Akaba there are many of these old reefs, indicated by the numerous white patches which protrude through the heaps of dark-coloured *débris* from the granite mountains, most of which are at much higher elevations than the one just referred to, some being especially visible on the flat plain near Omaider.

In confirmation of these indications of an elevation I may add that Captain Evans, a Commodore of the P. & O. Co's fleet, stated to me that in the Gulf of Suez there are reefs which twenty years ago could with impunity have been sailed over, but have now to be avoided, the two most remarkable of these being:—one at the entrance to the Gulf of Suez, where the soundings which were at one time 7 and 7½ fathoms, are now only 3 and 3½ fathoms; and the other at the head of the Gulf, called the Newport shoal, where there is a like decrease in depth.

I am told that indications of a shallowing of the water in these seas may be seen by comparing an old chart with one of recent construction; the origin of it, apparently, can only be accounted for in one of two ways—by an elevation of the sea-bottom, or a piling-up of drifted materials by currents.

As an additional proof of this rising of the land, I may quote from Dr. Beke the official report of the British Consul at Jeddah, on the Arabian Coast, who says "the sea on that coast is gradually receding, owing to the formation of coral reefs," the geological interpretation of which is evidently that the coast-line is being elevated.

That such elevations and perhaps oscillations should take place is not unnatural, considering the wonderfully volcanic nature of the adjoining peninsula of Arabia, examples of which may be seen in the Trachonitis of Wetzstein or the Hauran of Burton and Drake in the north, and the many traces of varied volcanic phenomena from the shores of the Persian Gulf in the east to Jemen in the south-west. In addition to these already known localities, it may be stated, on the authority of Jakut, the Arabian geographer of the thirteenth century, that many, although once chronicled, now remain to be rediscovered. No less than 28 harras, or volcanic districts, are described and their position identified by him, all of which are to be found in the highlands and interior of the peninsula. The list of these is as follows:—

Harra of Autâs.
„ Tabûk.
„ Takda or Nudka.
„ Hakl.
„ al-Himâra.
„ Ragil.
„ Rahis.
„ Ragla.
„ Rumah.
„ Sulaim.
„ al-Sarg.
„ Sauran.
„ Darig.
„ Dargad.

Harra of Abbad.
„ Udhra.
„ Asás.
„ Gallas.
„ Kuba.
„ al-Kaus.
„ Lubu.
„ Laflaf.
„ Lailā.
„ Másar.
„ Maitan.
„ Wakim.
„ al-Wabana.
„ Banu Hilal.

Referring to the above list I may quote the following paragraph from Br. Beke's pamphlet 'Mount Sinai a Volcano':—

"Among the numerous volcanoes found to exist within the Arabian peninsula, the only one known to have been in activity within the historic period is the Harrat el Nar ('fire-harra') situate to the north-east of Medina in the neighbourhood of Khaibur, in about 26° 30′ north latitude, and 40° east longitude; which, besides being traditionally said to have been in an active state six centuries before Mohammed, had actually an eruption in the time of the prophet's successor, Omar. To the north-west of this 'fire-harra' lies that known as the Harra of (the tribe of) Udhra: again, to the north of this, is the Harra of Tabuk, so called from the station of that name in the Hadj road from Damascus to Mekka, the position of which is about 28° 15′ north latitude and 37° east longitude; and beyond this last, further to the north, and consequently between it and the northernmost Harra of Râdjil, or Trachonitis, is the Harra Radjlâ."

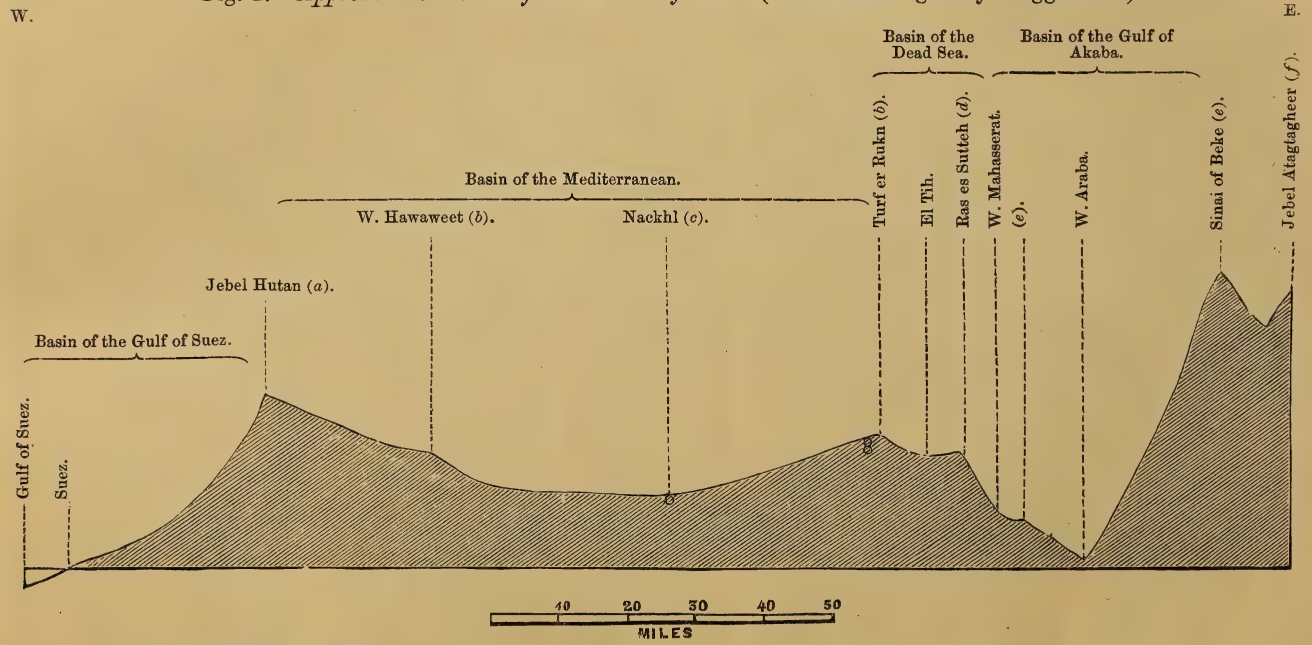
Rocks from Bir el Mashiyah.

(These are all taken from dykes. The first two have been determined microscopically.)

1. Diorite, a greenish-grey compact rock, the character of which is almost entirely disguised.
2. Felsite with epidote and chlorite. In general appearance this is a compact, fine-grained, light-green rock, not unlike an epidosite.
3. Porphyritic micaceous granite. The base of this, through which large white crystals of felspar are disseminated, is irregular in texture, being mostly composed of small flakes of a dark-coloured mica.
4. Porphyry consisting of a compact, dark purple base, and well-defined crystals of pink orthoclase.

Omaider to Akaba.—Opposite to Omaider on the Sinaitic side, flat-topped outliers are to be seen capping the granite. These are of a yellowish colour and apparently soft, and at this place show a regular stratification, dipping 3° or 4° towards the north. In the distance, between gaps in these hills a long flat-topped mountain or edge of a tableland is visible, apparently composed of the same material as

Fig. 1.—*Approximate Section of the Plateau of Tih.* (Vertical scale greatly exaggerated.)



(*a*). Nummulitic limestone.
(*b*). Limestone.
(*c*). Limestone like chalk.
(*d*). Red Sandstone, Limestone, and Flints.
(*e*). Granite.
(*f*). Granite capped with sandstone.

the outliers, which afterwards proved to be a soft whitish limestone. On the west coast these outliers are more or less continuous up to the head of the Gulf, whilst on the east side there is only the granite and its long heaps of *débris* stretching down towards the shore. Looking at these outliers from a distance, it is at once noticed that the granite surface on which they rest is invariably flat, showing that it had been planed down to an even surface before the deposition of the superincumbent beds, which in their turn, by the comparison of the flat tops they now cover with the adjoining serrated ridges of granite which at one time it is probable that they also overspread, show the immense amount of denudation that has been going on since their removal.

Wady Araba (see figs. 1 & 2).—When within five or six miles of Akaba, the relation of this Gulf to the broad and open valley of the Araba, leading northwards towards the Dead Sea, is strikingly observable. Although upon the east and west the ground is high, before one (to the north) it is so level that it is almost impossible to indicate the point at which the sea and land meet. Looking up this trench from the south, in the distance the mountains upon the right and left appear to grow lower, until by sloping downwards they finally vanish in two points upon a line forming an horizon for earth, sea, and sky.

Looking at the map, it will be seen that the Gulf of Akaba forms one extremity of a long north-and-south hill-bound trough, the other extremity of which is beyond the Lake of Gennesareth, at the northern end of the valley of the Jordan, a distance of more than 200 miles. An east-and-west profile across this trough taken a few miles above Akaba is represented by the eastern end of the section (fig. 1).

When standing in it you appear to be in an almost flat valley, about five miles in width, having no perceptible rise towards the north, but to the east and west rising gently towards the flanks of precipitous granite hills, its deepest portion, which is marked by a north-and-south line of vegetation, being nearer to its western side than to its eastern, as shown in the section. By actual observation, however, it appears that the boundaries, which are apparently hills, are only the serrated edges of two tablelands, which on either side rise about 2000 feet above the sea—broadly speaking, the western one being chiefly granite capped with limestone, and the eastern one being granite capped with sandstone and conglomerate. The consequence of this is that the high mountains as seen from Akaba and the Araba, are from the tableland comparatively low hills.

Taking a section from south to north, from Akaba up the Araba, through the Dead Sea and up the valley of the Jordan past Gennesareth (fig. 2), it will be seen that the greater portion of the surface of this ground is below the level of the sea, and all that separates the Dead Sea, which is in a depression about 1300 feet below the neighbouring oceans, from the Gulf of Akaba is a slight rise of from 200 to 500 feet.

Therefore, should there have been an elevation of the land in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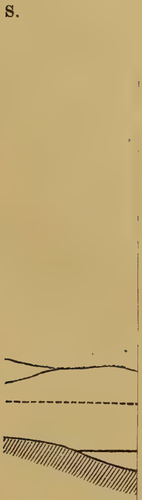
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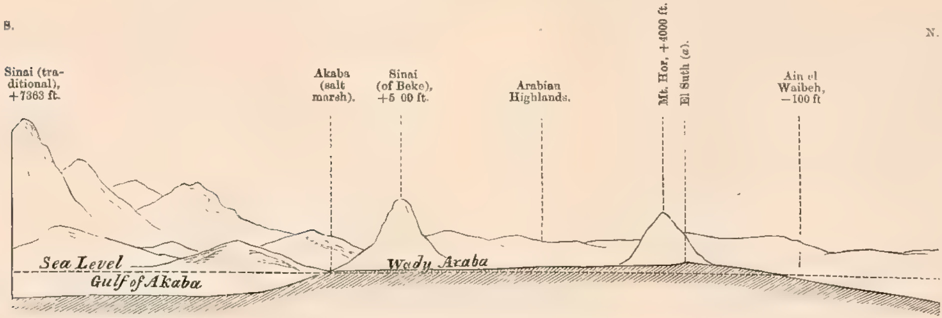
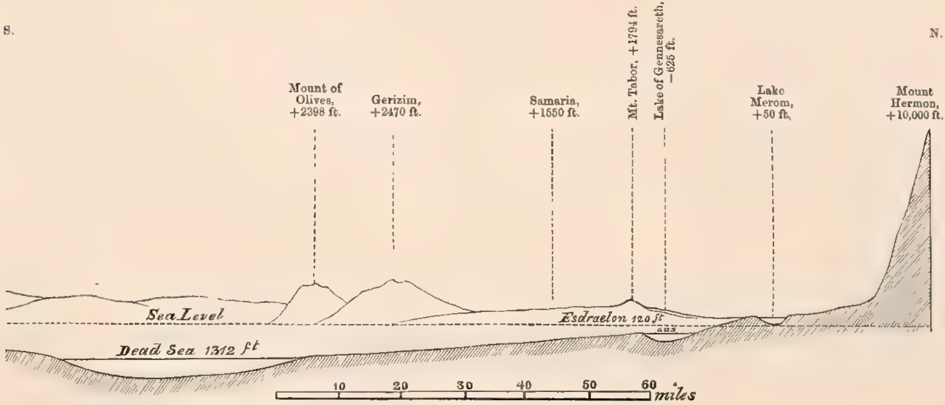
Fig. 2.—*Approximate Section from the Gulf of Akaba to the Valley of the Jordan.*



(*a*) The water-parting, under 500 feet.



operation, as appears to be indicated, it is very probable that at no very remote geological period the Gulf of Akaba extended many miles further to the north, having been bounded on its east and west sides by the before-mentioned high tablelands; and should this ancient gulf be restored (which would apparently be an engineering work far less difficult than the recently constructed trench between Suez and Port Said), Jerusalem, Damascus, and other Syrian towns would again be in communication with the Indian Ocean, and fleets like those of Solomon might ply up and down the now entirely deserted Gulf of Akaba.

The section illustrating this depression (fig. 2), which will explain itself, is only an approximation, and is here used to add my observations to similar ones that have been made by others on this singularly interesting depression.

Akaba.—At Akaba (fig. 2), as at many other places, the granite is traversed by so many dykes that they could not but take part in the formation of peaks. Their general direction is in a parallel line towards the north-east, and at a high angle of inclination to the south-east.

Behind Akaba, two good analogous sections are to be seen on the eastern side of Wady Araba, at the entrance to a small wady called Wady Ithm. The surface of the ground through which these sections are cut commences about half a mile from the sea, and terminates at a distance of a little over a mile, sloping at an angle of about 3° up towards the mountains. The distance apart of these sections at their upper or eastern end, where they are about 30 feet in height, is about 100 yards, and at their lower or western end, where they merge into the sloping plane through which they are cut, about half a mile.

Looking at these generally, they consist of a mass of earth, pebbles, and boulders, lying on the denuded edges of granitic rocks and felspathic dykes. The pebbles and boulders are of the same nature as the rocks on which they lie; and at the eastern end of the sections near the mountains it would appear that the pebbles, and especially the boulders, are not only larger but also more angular than those a mile further away.

The mode of accumulation of the upper stratum of alluvial material is strikingly shown at several points along the section. The material, starting from the mountains (which at one time probably extended a short distance westwards), through various causes, but chiefly that of gravity, gradually travelled down the slope towards the sea. On coming to a hollow it steadily filled it, the stones of each layer rolling over their predecessors until the original slope was regained, the result of which has been to give, at different points along the section, several groups of radiating bands.

The granite is of a pinkish colour, and consists chiefly of felspar and a little quartz, whilst the mica is barely visible. It contains numerous dykes, which vary from dark green to olive-green in colour. At the junction of several of these with the granite, and running through them both, are flakes of white carbonate of lime about

$\frac{1}{8}$ inch in thickness and having a glistening crystalline surface, which fill up joints in the rock. All the rock containing this carbonate of lime (not only the dykes but also the granite) crumbles under the hammer like a dry clay, whilst at the distance of a yard from the dykes, where this carbonate of lime does not exist, the stone is hard and compact, and when struck gives a sharp clear ring.

Rocks from Akaba.

(The first three of these were examined microscopically.)

1. Dolerite, large-grained, containing some acicular crystals, which are probably apatite. This is an even-grained compact rock of a reddish-grey colour.
2. Dolerite similar to No. 1; but the felspar is more degraded, and the rock itself of rather a darker colour.
3. Syenite with altered hornblende, orthoclase, a little triclinic felspar, mica and quartz. In general appearance the rock is very like Nos. 1 and 2.
4. Granite, of a pinkish-white colour, and with a scarcity of mica. From the vicinity of a doleritic dyke.
5. Granite, consisting of white and pink felspar, mica, and quartz.
6. Granite, with chlorite, and fissures filled with crystalline calcite.
7. Granite with more chlorite than No. 6.

From Akaba our journey eastwards was confined to Wady Ithm and the various wadies and plains which branch out of it.

General appearance of Mountain-Wadies.—These wadies winding in and out between the granite hills, may be described as narrow defiles of great length. They vary in width from 100 yards to half a mile, and wind in and out between almost perpendicular walls of granite, making the approach to every turn or bend in their course appear as if it were a terminus.

Under foot are large boulders, stones of various sizes, small pebbles and sand, giving the place the appearance of a dried-up channel, which formed the bed of some large and rapid river. On inquiry it was found that no body of water ever flowed down these defiles—a fact that might have been anticipated by observing that the beds of grit and sand were cut through by small channels not 6 inches in depth, instead of being left, as would have been the case in a river, in one flat stone-covered surface. Whilst amongst these mountains, I experienced three days of continuous rain, after which I did not see anywhere more than the faintest trickling of water—from which fact, in conjunction with others, I think we may conclude that in these wadies there are conditions very analogous to those of river-beds, but that in their formation water has played but little part.

Another striking phenomenon of these wadies is the presence of perfectly perpendicular walls of *débris*, which often form boundaries upon both right and left.

These walls vary considerably in their height; sometimes they are only 1 or 2 feet in height, but generally from 6 to 10 feet, whilst in many places, by actual measurement, they were from 30 to 60 feet, and occasionally even still higher. The lower ones (which are more generally met with) are formed of greyish gritty sand and small pebbles, and, as compared with the higher walls made up of sand, stones like cocoa-nuts, and large boulders, are of a noticeably fine material—the former looking like a face of Roman cement, and the others like a conglomerate.

The most striking point, however, about these walls, especially in those about 6 or 10 feet in height, is the almost perfect and unbroken square edge they form with the plain from which they descend, these clear edges being in lengths varying from a few yards up to 100 yards. Comparing the various walls together, it is seen that these several characters depend upon the fineness or coarseness of the materials of which they are composed; and it may be generally stated that their length, their fine finish, and the squareness of edge they form with the upper plain, vary inversely with their coarseness, whilst their height varies directly; the coarser the material, the higher the wall. In taking a section transversely to the length of one of these wadies, we may obtain a step-like outline descending from the mountains on either side; but more generally the form obtained is that of two rapid slopes from the hills, each terminating in a wall, leaving between them the level central part of the wady, described as being in some respects analogous to a river-channel. This central channel, in which the boulders, which are often of great size, are found lying in heaps and lines parallel to the bounding walls, may vary from 50 to 200 yards in width. From the same characters being often seen in opposite walls, it is probable that before an initial slope was formed, down which water and materials in general would tend to travel, they were joined from side to side.

Their growth into the truly perpendicular forms which they now present, evidently arises from the materials of which they are built up being so regularly disposed that there is nothing left to produce unequal disintegration; that is to say, a disintegration commenced at any one point is at once or very rapidly carried in a perpendicular direction equally over the plain in which the commencement of the disintegration took place, the materials being so loosely placed together that for support they are mutually dependent; take one particle away and its neighbour falls. This cliff-formation is strikingly seen in the lower and more common of these walls, which are made up of pebbles, grit, and sand. On attempting to walk within a foot of the upper edge of one of these, a vertical layer separates from the top of the wall and falls to form a conical heap below, which is afterwards removed by wind and water. In nature, however, instead of an external pressure acting on the upper surface, a similar result is produced by the action of the little water which occasionally trickles down these wadies, and still more by the almost continuous working of a sand-drift along the lower portion of the face of these walls, by which they are slightly undermined. When sufficiently undermined in this way (seldom more than 6 inches), the unsupported material above, having little or no lateral attachment to the contiguous mass, of necessity falls. After a little rain this action is strikingly rapid, the slight bond between the particles being loosened by the soaking-in of the water.

As these walls are cut further back and approach the hills, the mass of material in which they are formed being thicker, they are naturally higher, in addition to which it may be noted that they are also coarser and have lost much of their smooth finish, which latter character is apparently due to the larger masses of which they are built up having more hold upon each other, one of them not moving without disturbing its neighbour.

Had the materials of which these walls are built been interlaminated or cemented in any way, no portion of it could have given way without disturbing that which was contiguous to it, by acting on it as a cantilever.

This may be looked at generally by considering cliffs or walls the component parts of which are so arranged that their greatest length lies in a horizontal direction. In such walls, where we get this horizontal interlamination, whether of massive bands of rock, fissile shales, or only layers of stone, on their being undermined, generally speaking, no portion of them can give way without disturbing those parts with which they are in contact, especially those lying above, which, cantilever-like, they tend to prize upwards and then cause to fall outwards, this outward tendency being aided by the material from above slipping down over that which has fallen from below. The result of this is the production of a slope, instead of a clear perpendicular wall, such as is produced by the direct fall of an uncemented fine material.

The unbroken edges of these cliffs, although in part due to the nature and arrangement of the material of which they are formed, are also in part due to a cause similar to that assigned for the unworn edges of some of the American cañons, namely the comparative absence of rain—the little that does fall being hardly sufficient to affect those of coarse material, whilst those made of fine material are immediately soaked, and the undermined portions at once fall instead of remaining to be channelled down with gutters.

It has been observed that the great heaps and long lines of boulders so often seen in the centre and other parts of these wadies can hardly be thought to have assumed their rounded forms and to have come into their present positions by the agency of water (which at first sight is so suggestive both as a motive power and also as a polishing agent), the district being riverless and also, compatively speaking, rainless.

The reason of their waterworn appearance is apparently in great part due to the cutting effect of an almost perpetual sand-blast; but the cause of the central position they so commonly occupy is not so obvious. It may have been acquired by their having simply rolled down the sides of the mountains when they extended further into the wadies than they do at present; but in many cases it is probable that the descent was far more gradual. Whilst riding along the base of some of the cliffs of sand and conglomerate just described, on looking up, long lines of boulders were often seen waiting to be undermined and to fall below. Many could be seen that had fallen, whilst others were barely balanced and ready to topple over on the least disturbance.

Each time one of these falls it travels a certain distance forwards; and as cliffs are continually being formed in the centre of the wady to work back towards the hills, steps are continually approaching these boulders, down which they may roll and approach the central line of cliff-formation, where those from one side of the valley meet, stop, and accumulate with those coming from the opposite side.

Such modes of transit as these may be suggestive in accounting for the presence of erratic blocks so often seen not only in various parts of Arabia, but also in other countries, as, for example, in Persia, where they have been seen to have travelled distances of five and six miles—in certain cases, perhaps, giving a clue to those phenomena which otherwise might have found a satisfactory solution either in a coat of glaciers or a sea of icebergs.

In the cases quoted large blocks have apparently travelled distances of a quarter of a mile by the breaking down of about a hundred feet of modern alluvium. How far, it may be asked, would blocks have travelled had the strata measured thousands instead of hundreds of feet?

With regard, therefore, to the general appearance of the beds of these mountain wadies, it may be briefly stated, in conclusion, that their characters are, in the main, rather due to a stream of sand than to water; small furrows formed in the central parts of the wady retreat towards the hills by being undermined and then falling by their weight. By this falling, boulders, often 20 feet in diameter, are rolled forward, and strewn across the plain from the hills towards a central line in which they accumulate. Whilst all this is going on, an almost continuous draft of air up or down these funnel-like defiles is in operation, carrying sand to polish the scattered *débris*, thus helping in the production of appearances not unlike those of some ancient river-bed, in which action it is aided by a slight trickling of water after the winter showers.

Sand-blast.—Having spoken of the movement of sand as an agent in the undermining of cliffs and the polishing of rocks, although, perhaps, often before observed by others, I may here mention what was seen of its other effects in these districts.

A great portion of the country lying between Nackhl and Suez is covered with a thick superficial deposit of fine reddish sand, which, like all other sand, is set in motion whenever there is the slightest movement in the air.

This, although an almost perpetual action, is only to be seen under very favourable circumstances. By placing yourself so that the sandbank, or piece of ground you are observing, is between yourself and the sun, a slight smoke-like vapour, which from other positions would be invisible, is to be seen sweeping over the surface of the ground. The presence of this drift may also be recognized by placing the face within 10 or 12 inches of the ground, when fine particles of sand will be seen rolling along over each other; and on putting the ear near to these a slight rustling noise may often be detected.

By taking a flat piece of wood and using it as a straight-edge, I made several practically level patches of ground, on which I was enabled to see the action of the drift in the formation of ridges. Although when standing up no movement in the sand could be detected, yet on stooping down I perceived that ridges were being formed, not simultaneously over the whole surface, but commencing to windward. The crest of each of these small undulations appeared to be invariably covered with the redder particles of sand, whilst the yellow ones were left in the hollows.

In the case of larger ridges, which were about 6 inches in height, their crests were composed of the larger particles, which, as far as colour was concerned, could not be distinguished from those forming the hollows. Small movements of this description are constantly going on; but in a gale, judging from experience, the results must be considerably greater. When a moderately heavy wind is blowing, it is almost impossible to face the "blast." On your hands a tingling sensation is felt; and on lowering them towards the ground this rapidly and irregularly increases in power until they are within a foot of the ground, when it becomes unbearable, the feeling produced being not unlike that occasioned by drawing off the keeper of an electro-magnetic machine.

Another and more important action of the sand-drift is the cutting of the surface of all stones which are exposed upon the desert —a fact which has often before been noticed, and may be well exemplified by the Sphinx near Cairo, and two faces of Cleopatra's Needle at Alexandria. Portions which are buried, or otherwise protected, are not cut, the consequence being that almost every stone, when picked up, presents two surfaces which differ in appearance, one being uneven and rough, whilst the other is pitted and polished. In the district especially referred to, near Nackhl, where the stones scattered in the desert are chiefly limestone, the definite character given to them by this sand is such that it could not be seen without being remarked. All have a peculiar polish, looking as if they had been smeared with grease, a lustre nearly represented in the fractured surface of some specimens of witherite.

In addition to this, they are all, more or less, pitted with small cup-shaped hollows, which apparently indicate the softer portions of the stone. Some few have cut upon their surfaces curious worm-shaped furrows; whilst others have exhibited such differences in hardness that their softer portions have been so far cut into and carried away that the remainder is as ragged in its outline as the root of a tree, for which in many instances they might readily be mistaken.

Should these stones hereafter become completely buried, as many already are, future investigators will find in them marks as clearly indicative of their origin as the rounded forms of waterworn pebbles or the angular and scratched faces in beds of glacial drift. Just as we infer from the latter the existence of former glaciers, so will they infer the former presence of deserts and sand-drifts.

Rocks from Wady Ithm (the first five of these were examined microscopically):—

1. Diabase, dark greenish in colour, compact and tough.
2. Diabase, more compact than No. 1, from which it also differs in containing a small quantity of disseminated iron pyrites.
3. Dolerite, blackish green, dense and compact.
4. Hornstone, whitish green, compact, crystalline, traversed by fine fissures containing carbonate of lime.
5. Dolerite, greenish grey and compact.
6. Granite, pinkish in colour and with little mica.
7. Felsite, pinkish in colour, containing a very little hornblende.
8. Porphyry, a pinkish base, with white crystals of felspar and a very little hornblende.
9. Porphyry, differs from No. 8 in being slightly darker in colour.
10. Granite, greyish in colour, of a coarse texture, and somewhat porphyritic.
11. Granite, pinkish in colour, with bronze-coloured mica.
12. Porphyry, of a pink colour, with hornblende.
13. Porphyry, differs from No. 12, in being of a greenish grey colour.
14. Porphyry, fine-grained and without hornblende.
15. Granite, consisting of felspar, mica, and very little quartz.
16. Granulitic granite.
17. Quartz-porphyry, of a pinkish colour.
18. Porphyry, of a bluish grey colour.
19. Syenite, of a dark-green colour, containing very little quartz, and very little hornblende.
20. Porphyry pinkish grey and fine-grained.
21. Porphyry, with hornblende.

With regard to the granitic hills lying between Akaba and Petra, as they have so many points in common, a description of one of them may, in many respects, suffice for the remainder. The one selected is Mount Baghir, also known as Jebel el Nûr, or the "Mountain of Light," which by Dr. Beke has been identified as the true Mount Sinai (see fig. 2).

This mountain, which is situated on the east side of Wady Araba, and on the west side of Wady Ithm, which it overhangs, is about 100 miles in a north-easterly direction from the traditional Sinai, and 12 miles from the fortress of Akaba. In its general outline it is bold, terminating in three well-defined small peaks, which distinguish it from the surrounding hills. Measured from the plain, out of which it rises, it is about 3000 feet in height, or about 5000 feet above sea-level. It consists of a mass of red or pinkish granite, which in places where it is much weathered is of a dark brown hue. In those places where disintegration has been at work, the felspar and lighter mica have to a great extent been washed away, leaving a rough gravelly surface of quartz, which crumbles under the feet. This granite contains comparatively but little mica; and in places it merges into quartz and massive felspar alone. On the north-west side of the mountain a portion of the granite looks at a distance like a coarse brownish yellow sandstone, weathering with rounded surface, in which many cavities can be seen, generally about the size of a cocoa-nut. In several large boulders of this rock these cavities have so increased in size as to be now represented by small caves, one of which was about 20 feet in diameter and 10 or 12 feet in height at its entrance, sloping down with a dome-shaped roof and curved sides towards the back. No angular forms are visible, which shows that the granite has flaked off in curved laminæ. On striking this rock with a hammer it has not the clear ring of a solid stone, but gives a dull sound, owing to the surface being so disintegrated and having the tendency to split off in flakes, which can easily be separated with the sharp edge of the hammer.

The peaks on the summit of this mountain are composed of granite; the hollows between them mark the position and direction in which the mass is traversed by dykes; and it may be stated as a general rule for this mountain, that the dykes do not protrude above the granite, but all tend to produce hollows. One exception to this, however, was seen on the N.E. side of the mountain, near a well, where a dyke formed a clearly defined ridge running up towards the summit. These dykes, which are generally of a dark green colour, vary in width from 1 foot to 18 feet, and perhaps more. When struck with a hammer, in many places they appear to be quite earthy, crumbling up like dry clay. The general direction of these and others in the neighbouring mountains is from between north and east to some point between south and west, often striking in long parallel lines across ridges of the hills.

Rocks from Jebel Baghir (Sinai) (the first three of these were examined microscopically):—

1. Dolerite, much decomposed, of a dark colour, loose texture, and a greyish exterior, owing to the weathering of the felspar.
2. Dolerite, portion of a compact, hard nodule, taken from the interior of the dyke of which No. 1 formed part.
3. Diabase, passing from porphyritic to aphanitic. The rock is black and dense; no structure is observable.
4. Granulitic granite, a fine-grained mixture of quartz and felspar, with finely distributed mica.
5. Granite, fine-grained and pinkish.
6. Mica and felspar, with very little hornblende, the whole forming an irregular greenish mass.
7. Granite, of a pinkish colour.
8. Granite, nearly all felspar.

Dykes.—The prominent part taken by dykes in giving the characteristic ruggedness to these granite hills has already been partially noted, as will be seen from the following observations of Dr. Oscar Fraas, 'Aus dem Orient,' where, at page 15, he says, "When on the summit of Serbal, in a circuit of about 1000 metres, rather more than less, I counted from our pinnacle 47 peaks, or, as might be plainly seen from those which were nearest to us, so many dykes of diorite which stood above the mass of granite. In the course of the incalculable ages during which these points had been exposed to the atmosphere, they had offered a different resistance to the weathering than had the granite with its felspars; and therefore as many diorite teeth stood out from the granite bed of Serbal as you could count points on the mountain."

From the observations made on these dykes at the various localities visited, which in part are confirmed by the specimens collected, it would seem that they may be divided into two classes—those of a red colour, and those of a dark green or black.

As a general rule the former are the harder of the two, and stand up as ridges which can be seen running up the sides of the mountains and over their crests, or else appearing only as peaks, but in all cases producing serrations; whilst, on the other hand, the latter are generally soft and form trenches and hollows where the red ones would have formed ridges and peaks. Exceptional cases are to be seen where the black dykes are hard and have resisted degradation; but in the case of the red ones no exceptions were seen.

Both classes of these dykes, like the granites they traverse, are highly felspathic, the red ones being generally compact felsites or fine-grained porphyrites, whilst those of a darker colour are generally porphyries in which small crystals of felspar are imbedded in a dark-coloured base.

Traversing several mountains near to Jebel el Nûr, and noticeably one called Jebel Atagtagheer, there are large dykes 12, 14, and even 20 feet in width, almost wholly composed of a soft material; yet, through having hard exteriors, they stand up so as to form a well-defined wall-like ridge. Through being thus composed of a soft central part or core cased in between two slabs of a harder material, disintegration has acted more rapidly on the interior portion than on the exterior, and has cut them out into a trench.

Up one of these trenches I ascended Mount Atagtagheer (see fig. 1). The dyke was throughout of a dark-green material, but slightly lighter in colour on its sides than in the middle. Its width was about 12 feet; 6 feet of the central part was soft and crumbled like dry clay when struck with the sharp edge of a hammer, whilst the 3 feet of casing on either side into which it graduated was hard and tough, in fact much more so than the granite through which it pierced.

The result of examinations of different portions of such dykes as these is given in the following list of rocks from Jebel Atagtagheer, from which it would appear that the interior portions of these dykes are apparently more siliceous, contain more olivine, more magnetite, and are decidedly more calcareous than the exterior portions; but as these and other similar specimens are intended to form the subject of a future investigation, the present statement must be received provisionally.

Rocks from Jebel Atagtagheer (the first four of these were examined microscopically):—

1. Quartziferous dolerite, from the *exterior* of a dyke, of which No. 2 is the interior. This is a dense, olive-green-coloured rock, readily scratched by a knife to a light-green streak.
2. Quartziferous dolerite from the *interior* of a dyke, of which No. 1 is the exterior. This is of a reddish colour and more granular than No. 1, from which it also differs in being decidedly calcareous and magnetic, and apparently containing more olivine and quartz.

3. Basalt from the *exterior* of a dyke, of which No. 4 is the interior. This is a compact and almost black, even-textured rock, and is slightly calcareous.
4. Dolerite, much degraded, from the *interior* of a dyke, of which No. 3 is the exterior. This is a greenish grey, loose-textured, granular rock, which is decidedly calcareous and also magnetic.
5. Pinkish granite, through which the above dykes penetrate.
6. Porphyry, red crystals in a green base.
7. Porphyry, of a greyish colour, containing acicular crystals of hornblende.
8. Porphyry like No. 7, but with large crystals of hornblende.
9. Porphyry, a compact felsitic mass.
10. Porphyry, darker-coloured than No. 9.
11. Porphyry, fine-grained and of a lavender colour.

Geological Formations.—When on the top of Mount Baghir, on looking from the north, by the east, round to the south-east, flat-topped hills were seen which from their shape were at once suspected not to be granitic, or, if granitic, to be capped by some other material. This conjecture was confirmed by visiting the top of Mount Atagtagheer, on the summit of which there are two large patches of sandstone, each about 100 feet in thickness, which have apparently been deposited subsequently to the formation of the granite. The beds, which are nearly horizontal, have a parallelism with the gentle undulations of what appears to be the denuded surface of the granite on which they rest. In no place does the granite appear to penetrate into the beds above, or in any way to break their even line of stratification; nor, on the other hand, does the sandstone descend into any crevices or irregularly eroded cavities in the granite. The lower beds of this sandstone, which are about 3000 feet above sea-level, are composed of a coarse quartzose material very like that which would be derived from granite after the washing away of the lighter materials. The remaining beds higher up, with the exception of a bed near the summit, which is of a perfectly white, fine-grained, soft sandstone, are composed of a yellowish gritty sandstone.

Although carefully looked for, no organic remains were to be found. Scattered over the top of the mountain were some compact dark-coloured rocks, probably the remains of a dyke cutting through some neighbouring mountain from which they have been derived.

To the east and north of this mountain there were many flat-topped hills; and the beds, which here only formed caps, appeared in the distance to form the hills themselves, the cliff-like faces of which showed curious barrel-shaped outlines. This same formation, resting on the granite, is to be seen at the head of Wady Amran, where it stretches away eastwards towards the centre of Arabia, and southwards towards the somewhat similar beds which were seen at Madian.

It has been asserted, on very good grounds, that in this portion of Arabia there are still remaining evidences of several once active volcanoes. Should these be discovered, they will in all probability be found amongst the sandstones on the eastern side of the great Arabian watershed; for had they existed on the western side, some traces of them must have been seen in the beds of the wadies which so rapidly descend towards the Red Sea.

Akaba to Suez (see fig. 1).—The northern end of the Gulf of Akaba having its shores bounded by granite hills, the consistency of which is tolerably equal throughout, the disintegration carried on by the sea has not tended to produce such an irregular outline as would have been formed had there been more variety in their character. At the north-western part of the gulf, however, between Ras el Musry and Jezêret Faraûn there is a slight exception to this. Here some soft limestones coming down to the coast between granite hills have been cut back to form a small bay, whilst their boundaries stand out as two small headlands. The rock composing these points is greyish in colour and granitic in nature, but varies considerably both in tint and texture. Opposite to Jezêret Faraûn, or Pharaoh's Isle, it is somewhat pinkish, and contains well-formed plates of mica, of the size of a shilling, and even larger.

The limestone, which dips about 15° to the north-east, is in parts quite white; but the bulk of it is of a yellowish tinge. Near the granite, against the sides of which it evidently rests, there are beds of a strikingly bright pink colour. In places on this exposure, which is about 800 feet in thickness, it shows itself like a compact chalk; whilst in other parts it is earthy, but contains interposed bands of solid stone from 2 to 4 feet in thickness.

In the cliffs near Ras el Musry there are beds of irregularly shaped flints and fossil remains, of which only a fragmentary specimen of an *Echinus* was collected. The valley up which these limestones run, called Wady Musry, is identified by Dr. Beke as being Pihahiroth or "the entrance to the caves," traces of which are to be seen a few miles distant from the shore.

Leaving the Gulf of Akaba at its north-west extremity, the Hadj road, on which the pilgrims to and from Mecca annually travel, rapidly rises, being bounded on its north and south sides by long narrow reddish-coloured heaps of *débris*, made up, not only of granitic rocks, but also of fragments of limestone. A short distance beyond this the termination of these mounds is found in some reddish granitic hills, which for the most part are apparently porphyritic.

At about an elevation of 1000 feet you enter the upper part of Wady Musry, bounded on its western side by the continuation of the same range of limestone rocks seen between Ras el Musry and Jezêret Faraûn, dipping in apparently the same direction as before, 15° N.E.

The rock itself is compact in appearance, very like a hard chalk, and contains many fossil remains, portions of *Echini, Pectines* and *Ostreæ* being common.

On the east side of this valley are much-decomposed granite rocks, of ill-defined reddish and greenish colours, which merge from one to the other. Those of a reddish tint are felsites, and are, as usual, harder than the dark-green porphyries which they occasionally traverse.

Rocks from between Akaba and the Tih Plateau:—

1. Quartz porphyry with a green felsitic base, through which crystals of porphyry are disseminated.
2. Red porphyry.
3. Brown felsitic quartz porphyry.
4. Reddish brown porphyry.
5. Light-green porphyry.
6. Reddish purple porphyry.
7. Porphyry like No. 6, but with white crystals of felspar.
8. Basalt, of a dark green colour and thoroughly degraded.
9. Red quartz porphyry.
10. Greenish grey porphyry, much decomposed.
11. Altered pyromeride, of a yellowish colour, and with a mamillated surface.

A short distance further up this wady, at an elevation of about 1200 feet, the road suddenly turns to the left through a narrow gorge of chalk cliffs, and then ascends by a steep, zigzag, artificially formed pathway to the plateau of the Tih.

Both on the right and left side of this defile good exposures of cliff-sections are to be seen, in which there are several inaccessible cave-like openings. The rock, as before, is lithologically a chalk, containing numerous bands of flint.

These bands, which can be broken out in large slabs, the upper and lower surfaces of which are gently rounded into smooth undulating surfaces, average about 4 inches in thickness, and occur at about the same distance apart. Although they can be detached in large flat masses, through the number of vertical cracks by which they are traversed, they split into fragments when struck.

On the surface of this chalk rock, in one or two places, a slight efflorescence of common salt can be detected—an indication, perhaps, of the existence of larger quantities in the neighbourhood.

About 80 or 100 yards up the gorge the chalk rocks suddenly terminate, and abut against the almost perpendicularly downturned beds of a yellowish rusty-looking limestone, the juncture of the two apparently marking the line of a N.N.E. fault.

In these yellow limestones flints were seen, and fragmentary fossil remains were common. All exposed surfaces of this rock are much eroded and weathered. In several large blocks which had fallen from some bands in the upper portion of this cliff-like exposure, small crystals of brown oxide of iron (pseudomorphs of iron pyrites in combinations of the cube and octahedron) were common.

At an elevation of 1800 feet, or 600 feet above the gorge, a bluish grey, compact, fine-grained limestone is met with, in which numerous sections of *Nerinæa* are to be seen. A few small cavities filled with minute scalenohedral forms of calcite indicated the existence of other fossil forms.

At 2000 feet there is an exposure, about 40 feet in thickness, of yellowish earthy bands, containing narrow veins of gypsum from 1 to 2 inches in thickness, forming a cap to the *Nerinæa*-limestone.

From this there is a descent of about 100 feet into a small open plain, in which there are numerous exposures of a pinkish red (or pale *maroon-coloured*) sandstone. In the portion examined this was made up of a fine-grained quartzose material, containing a small quantity of lime, probably derived by infiltration from the calcareous beds with which it is so closely associated. One exception to the colour of these beds was seen in a soft and friable yellow band. The left side of the road, which is here in part an artificial formation, is built up of blocks of red sandstone, which were obtained in large regularly squared oblong masses by undermining several overhanging beds upon the right. In these red beds, as might perhaps have been anticipated, no trace of organic remains could be seen.

On nearing the summit of the tableland of the Tih, which by barometrical observation is about 2000 feet above the sea-level, a view looking down into a north-and-south gorge showed the relation of the red sandstones to the limestones before described. Upon the east flat surfaces of limestone were seen dipping sharply towards the east; and from these scarps, and especially from the one forming the right-hand wall of this north-and-south gorge, it would appear as if they once covered over the nearly horizontal sandstones on the left.

Descent of the Tih.—The striking feature of this desert plateau, when approached from the Akaba side, is its wonderful evenness of surface, which, from the fineness of the material with which it is covered, gives it an appearance not unlike an immense expanse of gravel walk. This material consists in great part of white quartz pebbles, which are intermingled with fine-grained porphyries and other felspathic rocks derived from some low peaks several miles away to the north. About eighteen miles across this flat country, at Turf er Rukn, the track enters between low hills forming the southern boundary of this great tableland, the surface-contour of which, at this point, is represented by the letter V, the arms of which form a shallow trough-like drainage-area, one arm trending N.W. towards the Mediterranean, and the other to the N.E., towards the southern continuation of the Dead Sea, whilst the apex of the two is to the south.

Turf er Rukn, which is continued towards the north as a low and almost imperceptible rise of ground forming the water-parting between the V-shaped arms of the Tih, further to the south rises about 400 feet above the plain as a long scarp of yellow limestone. Near the foot of the southern end of this scarp there is a small exposure of a yellowish sandstone, and also indications of a band of siliceous hæmatite running in a direction about one point to the south of west. This ore is easily distinguished by its dark colour, which contrasts strongly with the light-coloured sand on which it lies.

Beyond this, upon the right or north side of the road, there are some low ridges consisting of bands of limestone dipping towards the north. Intercalated with these bands are layers of flint which, on their exterior, very much resemble some dark-coloured portions of the rock in which they are imbedded.

This character of country, of limestone scarps on the left, and low ridges on the right, through which occasional glimpses of the great plateau of the Tih are to be seen, continues for nearly a day's journey.

After passing Jebel Duppa the ranges on the right, growing higher, show a more definite character as compared with those upon the left. Whilst the latter remain horizontal, the former are almost turned on end, dipping at an angle of 45° to the north. They consist of limestones which are whitish at their base and yellowish near their summit. With them there are bands of flint, which, being tilted up with the rock in which they are stratified, stand up along the ridges of the hills, forming low parallel walls to hollow troughs. Numerous angular and apparently freshly broken fragments of these flints are strewn over the plain below, apparently broken by the more or less sudden expansion and contraction occasioned by the great variations in temperature, this action being probably aided by a jointed structure in the flint at the time of its removal from the limestone. That there are such variations in temperature may be inferred from the fact that many nights when we were in the desert the thermometer sank below zero, and shrubs and other objects were in the morning covered with a thick coating of hoar frost, this low temperature being invariably followed shortly after sunrise by a heat that readily scorched and peeled the skin from the face.

In addition to this it may be mentioned that several rounded and apparently whole flints were seen, which, on being touched, fell to pieces, showing them to have been broken by some force that had not been violent in its action, but had simply divided them and not scattered the fragments.

Materials being in this way continually supplied from a mountain, then being broken by the sun and afterwards buried in the sand, may perhaps give a clue to the origin of certain breccias.

At the western end of this range there is a large and well-defined wady stretching away to the north-west into a low undulating country of chalk-like rocks. At the entrance to this there is a small, solitary hill of chalk resembling an island, and showing the steep northern dip which characterizes the rocks along the southern side of this portion of the Hadj road.

At less than a mile past this a cutting has been made through a hill composed of fine-grained and perfectly white chalk, which gives a small but clear section of this rock, showing on its walls and also in the ground over which you walk, a great continuity of bands of flint.

Looking at the upturned edges of these bands upon the floor of the cutting, in places they are seen to have been divided and then reunited, forming cavities which are filled with a material in appearance like the surrounding rock. At several points along the walls of these cuttings numerous irregular, coral-like concretions stand out, through the weathering away of the softer material which once surrounded them.

On the left-hand side of the road it appeared as if the upturned chalky strata just referred to abutted against the horizontal yellow limestone which forms a more or less continuous ridge from Turf er Rukn to this point.

From the summit of any of the hills upon the right an extensive view of the greater portion of the Tih plateau is to be seen. Beyond the low water-parting which separates the drainage of the Mediterranean from that of the Dead Sea, towards the north and north-west are broken scarps of white rock, probably of the same kind as the hill on which you stand, showing numerous pyramid-like peaks and short ridges, at least 14 or 15 miles distant. These cliff-like forms are continued round to the north-east, but in this direction are apparently not only higher but much further away, being apparently 25 or 30 miles distant, and forming a terminal scarp to the southern extremity of Negel or the South Country. The most conspicuous object is Jebel Baredj, bearing about W.N.W. With a glass several hard horizontal bands could be seen standing out, forming small scarps intermediate between the peaks of its conical summit and the sloping talus below.

In a direct line south from this mountain there is a north-and-south section, showing an anticlinal of limestone dipping at a high angle to the N.W., and to the S.E. being completely turned over.

After passing Bir el Kureis (a large artificially formed well, holding a continuous supply of water for the use of the Hadj pilgrims, which is sunk in the bed of a shallow wady of the same name), the road gradually ascends, through the range forming the southern continuation of Jebel Baredj, into Wady Dritt. Here the low scarps which bound either side of this low valley, exhibit an extremely fine-grained white carbonate of lime, in texture much superior to the bulk of our English chalk.

From Wady Dritt to Nackhl, the halfway station between Akaba and Suez, the country, which gently descends, is generally flat, the even contour being broken only by a few white scarps upon the right and left, and some shallow wadies which cross the road at right angles. These wadies of the desert are shallow basin-like trenches, which, although they mark the line of drainage by the few bushes they contain, are very different from the well-defined river-like wadies seen amongst the mountains.

A few miles on the Akaba side of Nackhl there are several small but bold hills of chalk, the most conspicuous of which is Jebel al Kheimatein or the "two tents," so called from its shape. The road near this mountain is crossed by several veins of crystallized carbonate of lime about 6 inches in thickness, which, being more durable than the chalk through which they pass, stand up in bold ridges.

Nakhl to Suez.—From Nakhl the road towards Suez gently rises about 150 feet through a gap in the summit of the range of hills, which are seen to run like a line of white chalk cliffs from west to north. From this point a day and a half is spent in crossing a wide and open shingly plain traversed by a few north-and-south shallow wadies, until Wady Hawaweet, descending from Jebel Heîtan, is reached.

On the south side of the entrance to the wady there are horizontal bands of limestone projecting through slopes of débris, about 350 or 400 feet above the surrounding level. The rock has here lost its chalk-like appearance, and is a compact limestone. Near the foot of the wady many *Ostreæ* and other fossil forms are observed; and at about 300 feet above the plain there are bands almost wholly made up of a small *Echinus*, varying in diameter from $\frac{3}{4}$ inch to about $1\frac{1}{2}$ inch. At about 350 feet the summit of the pass is reached, from which point there is an almost continuous descent towards Suez, the rocks dipping about 15° to the S.S.W. Mr. Etheridge considers that these bands are probably of Miocene age.

Whilst descending on the Suez side of the hills down Wady Sagarah, the *Echinus*-bed is again passed. In places the limestone, which contains irregular concretions of flinty matter, is of a deep red colour, which is due to oxide of iron.

At Ras el Gibal this wady opens out into a small and fertile plain cultivated by the Bedouins, on the south-west side of which there are ranges of white rock which appear to be Nummulitic. After leaving this plain, the whole of the way to Suez is covered with hills of drift sand.

Conclusion.—On account of the hurried nature of my journey, it would not be advisable to make any definite statement as to the identification of the geological horizons which were passed over; but it will be seen that, on lithological and scanty palæontological evidence, the series of rocks mentioned in the foregoing account will bear comparison with the succession summarized by Mr. Bauerman as occurring further to the south (Quart. Journ. Geol. Soc. for 1869, vol. xxv. p. 17).

The few fossils collected are at present in the hands of Mr. Henry Woodward, F.R.S., of the British Museum, who has kindly undertaken to examine them.

With regard to the crystalline rocks, it will be seen that the prevailing feature in them is the predominance of the felspathic element in the granites and in the dykes by which they are traversed.

It will also be seen that out of the seventy-seven specimens examined, only two approximated to a syenite; nor were there any massive hornblendic rocks of this description seen in the district visited. In the Journal of the Royal Dublin Society for January 1858, there is a communication on a "Mineralogical Excursion from Cairo into Arabia Petræa," edited by Professor Haughton. Accompanying this there is a collection of rocks verifying the observations, from which it would seem that although syenite does exist in the Sinaitic Peninsula, it does not form a predominant feature; and it is also stated that "all the mountains in the neighbourhood of Sinai are granite." Such being the case, it seems hardly justifiable to attempt an alteration in the name of the rock, although syenite is not found at Syene on the Nile.

2. NOTES *on the* PHENOMENA *of the* QUATERNARY PERIOD *in the* ISLE *of* PORTLAND *and around* WEYMOUTH. By JOSEPH PRESTWICH, Esq., F.R.S., V.P.G.S., &c. Professor of Geology in the University of Oxford. (Read June 10, 1874.)

[PLATE I.]

IN their well-known paper on the Geology of Weymouth, Buckland and De la Beche [*] give but a very brief notice of the Quaternary beds of the district. They observe that there are no very "extensive and continuous beds of gravel," and that "the largest deposit of diluvium we have noticed is at Upway Street, four miles north of Weymouth; but in smaller quantities and irregular patches it is disposed over the whole surface of the country, on the summits and slopes of the hills as well as in the valleys." These scattered drift-beds are all referred, as usual at the time, to one great inundation, which excavated the valleys and overspread the country with patches of diluvial gravel.

Mr. Bristow, in 1850[†], recorded the presence on the top of the cliff at Portland Bill of a recent conglomerate, which Mr. Weston in 1852[‡] described as a "marine shingle," consisting "of beach-pebbles (with a few chalk flints);" and in 1860 Mr. R. Damon[§] mentioned that it contained in places "numerous shells of species now living in the neighbouring sea."

Mr. Whitaker[||] was the first to give, in 1869, a more particular account of this beach, and to specify the occurrence of *Littorina litorea*, *L. littoralis*, *Patella vulgata*, and *Purpura lapillus*, extending on the east side of the Bill for a distance of half a mile northward. Over the beach Mr. Whitaker noticed near "Cave Hole" the presence "of a head" (the waste of Purbeck and Portland beds) consisting of pebbles of limestone, flint, and chert; and at another place, of a yellowish brown loam with "*Bithinia* and *Pupa*."

In 1870, Mr. Pengelly pointed out the occurrence, in this raised beach, of Budleigh-Salterton and "granitoid" pebbles, and gave a list of seven shells[¶].

With respect to the occurrence of mammalian remains, the only specimen mentioned by Dr. Buckland[**] as having been found in this district was the tooth of an elephant, picked up on the Chesil Bank. The first notice of such remains in Portland was made in 1852 by Mr. Neale[††], who states that fragments of bones and teeth had been found about 400 feet above the sea-level, in a superficial deposit, red at top and passing into a black sand with large round black blocks of stone. The only species named is "horse;" but I find that Mr.

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[*] Trans. Geol. Soc. vol. iv. 1836, p. 44.

[†] Geological-Survey Map.

[‡] Quart. Journ. Geol. Soc. vol. viii. p. 1.

[§] Geology of Weymouth and the Island of Portland, p. 141.

[||] The Geological Magazine, vol. vi. p. 438.

[¶] Trans. Devonsh. Assoc. Sc. Lit. & Art, 1870.

[**] *Op. cit.* p. 44.

[††] Quart. Journ. Geol. Soc. vol. viii. p. 109.

Neale subsequently sent to the Society other bones, and amongst them the tooth of an elephant.

About twelve years ago, in making the deep dry moat (60 to 70 feet deep) on the south side of the Verne Fort, numerous large fissures, some open at bottom but closed at top, and some entirely filled with *débris,* were met with, traversing the Portland stone in a direction nearly north and south; and in the open ones, amongst a talus of broken fragments of rock, there were found* numerous bones belonging to *wild boar* (a very large species), *ox* (a large species), *deer, horse, wolf, sheep,* and several small animals. In addition to these there were in the collection, when I visited it, a skull and bones of *red deer,* a metacarpal bone of *Cervus megaceros* (?), skull of *Bos longifrons,* and skull of *dog.* All the bones are rather light, white, and do not adhere to the tongue. There is reason to believe that they are all of comparatively recent date, and have fallen into the crevices while they were open to the surface. Mr. Damon also notices the occurrence of gravel with teeth and bones of the mammoth at Radipole, and of a drift with land and marine shells in the cliff, 10 to 12 feet above high water-mark, at the mouth of the Preston valley†.

This, I believe, embraces all the information we have on the superficial deposits of this district. I had visited Portland in 1863, when, in consequence of some extensive quarrying which had been temporarily carried on to the west side of the Bill, some remarkable sections of the raised beach, varying considerably from the better-known portions on the east side, had then been recently laid open. A visit I made last autumn of a few weeks to Weymouth has enabled me to examine it more in detail, and to notice other phenomena connected with the Quaternary deposits, which I think of sufficient interest to lay before the Society.

The general features of the district are well known. The bold chalk escarpment, 500 to 600 feet in height, of the Isle of Purbeck, ranges to the coast at Lulworth, passes westward, four miles north of Weymouth, to near the sea at Abbotsbury, where it turns inland and northward. A lower undulating triangular tract of Jurassic strata stretches from the base of the last half of this line southward to Portland (see Map, Pl. I.). At a short distance from its southern extremity stands Weymouth. None of this tract rises higher than from 250 to 300 feet, while near Weymouth the hills are generally not more than from 50 to 100 feet in height, and the narrow neck of land connecting Portland with the mainland would be on the sea-level, were it not for the Chesil beach, which rests on it and rises 40 feet above that level. At the end of the narrow neck of land the Isle of Portland rises abruptly to the height of 500 feet at the Verne, from which point it forms a gradual incline to the Bill, a distance of four miles, where the cliff ends with a height of 25 feet.

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* Damon, *op. cit.* p. 130.

† This latter I could not find. It may have been removed by the wear of the cliff. Mr. Osmond Fisher, however, informs me that elephant-remains have been found at low water on the shore at Preston.

We thus have the elevated range of the chalk on the one side, and on the other the high and nearly precipitous cliffs of Portland, with an intervening area at a lower level, presenting almost everywhere a bare denuded surface of Jurassic strata.

Portland Mammaliferous Drift (*f* on Map and Sections, Pl. I.).

The Isle of Portland also exhibits a singularly bare and denuded surface, with the exception of one small spot on the top of the island, which was discovered in the progress of quarrying (it has now been nearly removed) in the eastern part of the Admiralty quarries. I was obligingly conducted to the section by Capt. Clifton, Governor of the convict prison, in whose collection I had seen some specimens from it which were new to me, and to whom I am indebted for many particulars of the deposit, which he had noted before its removal. It was from this spot, we may presume, that Mr. Neale obtained his specimens. The ground is here about 400 feet above the sea-level, and a few hundred yards south of the Verne, where the summit-level is reached at a height of 500 feet. The Portland stone is extensively quarried; and over it is a capping of from 10 to 15 feet of unfossiliferous Lower Purbeck. The mammalian drift occupied an irregular trough in the Purbeck and upper part of the Portland beds.

Capt. Clifton informs me that, when first discovered, the deposit occupied a depression in these rocks, with a surface level with theirs. It was from 10 to 20 feet thick, with a width of from 50 to 60 yards, and extended N.E. and S.W. for a distance of from 200 to 300 yards. I found the remaining part of it in patches between, and spread over, the large waterworn blocks and surface of the upper Portland rock. The deposit consisted of a red clay or loam, passing into a coarse loess, in places full of angular local *débris* of the Portland and Purbeck beds, together with a considerable number of small blocks (some a quarter of a ton in weight) of the hard sandstone or sarsen-stone* of the Lower Tertiaries. At a few places this was underlain by a singular layer of pebbles, waterworn and perfectly rounded, and in a matrix of sand and red loam mixed with a large proportion of peroxide of manganese, whilst they were occasionally cemented together in a thin layer of calcareous spar. The pebbles so encased presented a perfectly clean and bright surface, as though they had been artificially polished. In this deposit I found:—

	Origin.
1. Small round flint pebbles	*Tertiary.*
2. Rolled and subangular fragments of ironstone grit	
3. Small subangular fragments of very hard sandstone	
4. Imperfectly rounded blocks of ditto	
5. Small angular fragments of flint	*Chalk.*
6. Well-rolled rounded pebbles of chert	*Upper Greensand.*
7. Subangular fragments of chert	
8. Subangular fragments of black flint	*Portland.*
9. Quartz pebbles	*Old Gravel?*

---

* Much worn and stained reddish brown, and sometimes blackened by oxide of manganese.

It was in the lower part of this deposit that the mammalian remains were found. I am informed that they were extremely numerous, and that a very large number of teeth of elephant were obtained at the time; but, with the exception of the few specimens preserved by Capt. Clifton, and the specimens sent to the Geological Society, I have been unable to trace any of them. They are, with few exceptions, in a very fragmentary state. Mr. Busk, who has had the kindness to examine them, reports that

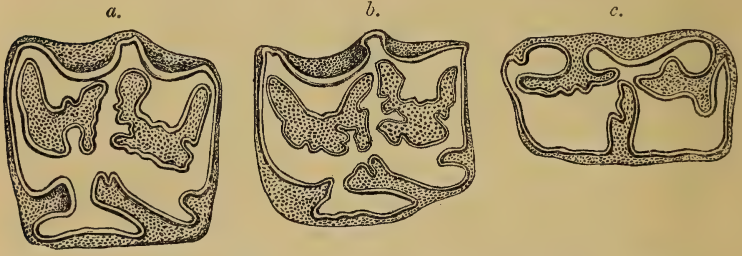
"They include a well-marked molar of *Elephas antiquus* and fragments apparently of a large molar of *E. primigenius.*

"The remainder appear to belong to the horse (fig. 1), and, from the pattern of the teeth, of the ancient form termed *Equus fossilis* by Owen (Br. Foss. Mamm. p. 383), characterized by the somewhat greater plication of the enamel folds—a distinction perhaps of no very great importance, but showing a tendency towards the still more complicated pattern of *Eq. plicidens,* probably another form, from the Oreston fissures.

"In his account of the Bruniquel cave, Professor Owen calls a very similar form *Eq. spelœus.*

"The third figure of the three (fig. 1, *c*) very closely represents that shown in fig. 7. pl. 57 of the Bruniquel memoir.

Fig. 1.—*Teeth of Horse* (Equus fossilis ?).



a, b. Upper molars. *c,* Lower molar.

"In condition all the bones appear to be of extreme antiquity; and they are more abundantly infiltrated and coated with oxide of manganese than any I remember to have seen."

Besides some species which cannot be determined, the list consists of:—

Elephas antiquus.
Elephas primigenius ?
Equus fossilis ?
Equus spelæus ?
Cervus.
Bos.

The pebbles and mammalian remains were confined to the small area before named in the Admiralty quarries; but the red loam may be traced from the tank in the Verne, at a height of 450 feet, to the old quarry opposite the new prison church, where it is at a level of 360 feet—a distance of five sixths of a mile. I could not find a trace of this interesting deposit in any other of the quarries or sections of the island. The Purbeck beds everywhere present a bare and broken surface.

The Raised Beach (*e*, Map and Sections, Pl. I.).

This beach extends on the east side of the Bill, exactly one mile from the Sand-holes near Southwell to the "land-mark" at the Bill, and appears to range about a furlong inland, passing under a covering of sand, loam, and rock-débris. From the Bill it extends along the west cliff for a distance of about a quarter of a mile, when it ends against an old subsoil cliff.

This old beach is most largely developed and thickest on the west side of the Bill; but it there scarcely contains a shell. It is a mass of well worn and rounded shingle from 5 to 10 feet thick. On the east side, where the coast recedes and was more sheltered from the western gales and drift, the beach is reduced to 3 or 4 feet.

At the Bill it is only 24 feet above the the present beach. It gradually rises as it trends northward, and is 36 feet above the shore near its north-eastern extremity, and 53 feet at its north-western extremity *. Shells are very numerous at places between Cave Hole and the Sand-holes, but become scarcer on approaching the Bill, and are very rare on the west cliff, where the beach consists of a mass of compact well-rounded shingle, and with little or no sand, whereas on the east side there are also overlying patches, from 1 to 3 feet thick, of shelly sand, full of small shells in a beautiful state of preservation, and in places dug out in small holes. At this part of the beach shells are extremely abundant, especially *Littorina*, *Patella*, *Purpura*, *Ostrea*, and *Mytilus*, and the original colour of the shells is in many cases in great part preserved. On examining the sand I also found it extremely rich in small species, several of which are new to our raised beaches. The following is the list, for which I am indebted to Mr. Gwyn Jeffreys's obliging assistance:—

BIVALVES.

1. Anomia ephippium, *Linné.*
2. Ostrea edulis, *L.*
3. Mytilus edulis, *L.*
4. Modiola marmorata, *Forbes.*
5. Cyamium minutum, *Fabricius.*
6. Tellina balthica, *L.*
7. Saxicava rugosa, *L.*, var. arctica.

UNIVALVES.

8. Patella vulgata, *L.*
9. Tectura virginea, *Müller.*
10. Trochus helicinus, *Fabr.*
11. —— cinerarius, *L.*
12. —— umbilicatus, *Montagu.*
13. Lacuna portiolus, *Turton.*
14. Littorina obtusata, *L.*
15. —— rudis, *Maton.*
16. Littorina litorea, *L.*
17. Rissoa parva, *Da Costa*; and var. interrupta, *Adams.*
18. —— striata, *Ad.*
19. —— subcylindrata, *Jeffreys*, sp. n.
20. Skenea planorbis, *Fabr.*
21. Purpura lapillus, *L.*
22. Buccinum undatum, *L.*
23. Nassa incrassata, *Müll.*
24. Utriculus truncatulus, *Bruguière.*

FORAMINIFER.

Miliola seminulum.

CRUSTACEAN.

Cythere, sp.

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* Measured from top of present beach to top of raised beach.

To these Prof. Rupert Jones has added *Polystomella striatopunctata,* and a *Cythere,* sp. nov. (?), but related to some known forms.

A curious feature in this old beach is the occurrence of thousands of the tiny *Cyamium minutum.* This species is "gregarious among seaweeds and under stones at low water," and "has a high northern range; but its southern distribution is limited"*. The other species are common on the western coasts of Europe, and inhabit the littoral zone. They are all to be found, with one exception, in Mr. Damon's list of the shells of the Weymouth coast†.

The beach on the west cliff is very thick and massive, but contains very few shells. Mr. E. Cunnington, who was with me in 1863, found one specimen of *Buccinum undatum,* var.; and I obtained a few fragments of *Mytilus*; but we found no others.

The shingle of the raised beach is composed, in great part, of chalk flints, with which are mixed some pebbles of the harder beds and of the flint of the Portland rocks, together with others of a more distant origin, the following being the order of relative frequency and character of the pebbles forming the shingle, with the source whence they are derived:—

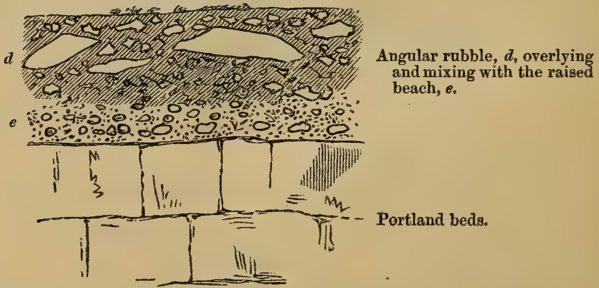
1. Subangular fragments of flint	*Chalk.*
2. Chert	*Upper Greensand.*
3. Ferruginous grit and sandstone	*Lower Tertiaries.*
4. Hard sandstone	
5. Red and purple sandstone	*New Red Sandstone and its conglomerates.*
6. Grey and red quartzite pebbles	
7. Dark-red porphyry with large crystals of felspar	
8. Light-red porphyry with small ditto	
9. Micaceous sandstone	*Devonian?*
10. Light-red granite	*Cornwall?*

With these I found on the east side two large boulders, one of which might be referred to a Tertiary sandstone, and the other to the Calcareous Grit.

Deposits over the Raised Beach.

At the Bill the raised beach caps the cliff, and is not covered by any other deposit, or only by a broken local débris; but as we trace

Fig. 2.—*Section on top of cliff near the Boat-haul, Bill of Portland.*



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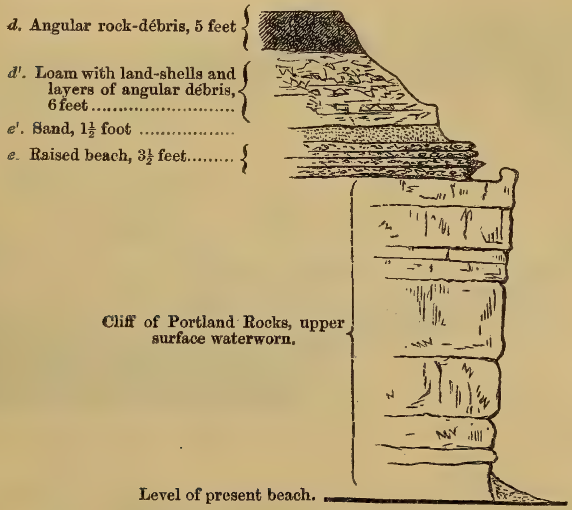
* Jeffreys's 'British Conchology,' vol. ii. p. 261.

† *Op. cit.* p. 175.

the beach to the northward, we find it passes under a light-coloured loam with seams of angular débris, succeeded by a mass of angular débris, chiefly of the local rocks (fig. 2).

On the east cliff the relation of the several deposits is not well shown. Still the order of succession is sufficiently apparent, and near the Sand-holes the section is as under (fig. 3).

Fig. 3.—*Raised Beach, with overlying angular land-débris, loam, and sand, near the Sand-holes, east side of Portland Bill.*



It is, however, on the west cliff that the finest section is exposed. Proceeding north-westward from the Bill, the beach is seen to pass under the loam with the overlying rubble-bed before mentioned. The loam varies in thickness from 10 feet at the northern end, to nought at its southern end, and contains subordinate seams of the same angular débris, giving it an appearance of rough stratification. In this loam I found, in places, seams containing considerable numbers of land and freshwater shells, but only of the few following species (determined, with the others, by Mr. Gwyn Jeffreys):—

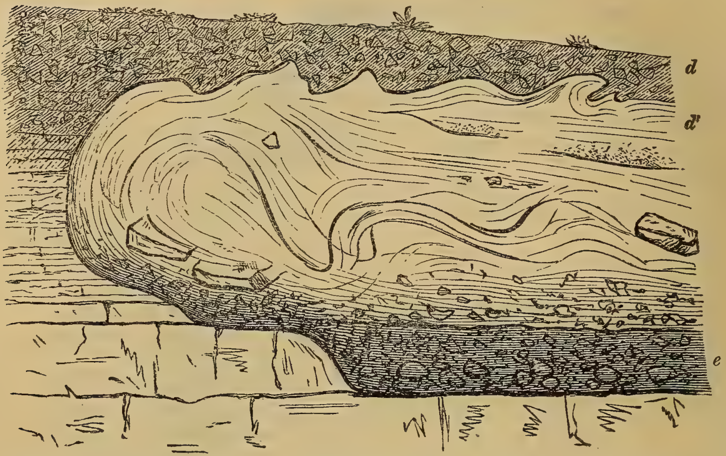
1. Limnæa peregra, *Müller*.
2. —— truncatula, *Müll.*, var. spira producta.
3. Limax agrestis, *Linné* (shields).
4. Succinea oblonga, *Draparnaud*.
5. Pupa marginata, *Drap*.

I found only one small fragment of bone, and derived (Jurassic?) specimens of a species of *Cythere*.

But the most interesting part of the section is that exposed just beyond the point to which the quarrying has been carried, and where the beach ends by the side of a large fissure which runs inwards from the shore.

On the surface there is nothing to indicate any change, the ground continuing its gradual slight slope from north to south. Descending, however, down the cliff to where the rock has been quarried near the fissure, the old beach, covered by the light-coloured loam, is found to abut against an old cliff of Lower Purbeck strata, the upper part of which is doubled back, and its débris thrown over the loam and carried southward, as shown in the following section (fig. 4).

Fig. 4.—*Section of Raised Beach and Old Cliff at the top of the present cliff on the west side of Portland Bill.* (See also Sect. 4, Pl. I.)



d. Angular débris, 4 feet. *d'*. Light-coloured loam with seams of débris and angular blocks; land and freshwater shells in places: 11 feet. *e*. Raised beach with very large pebbles at base, 7 feet.

This overlapping mass of débris extends all over the line of old cliff, which it has levelled with the surface from this point to its termination near the Sand-holes on the east cliff. To the southward it gradually thins out as it recedes from the old line of cliff, and ranges seaward over the old beach; but still it is clearly traceable in places as far as the land-mark at the extremity of the Bill, where it mixes with the upper part of the old beach.

This bed of rock-débris is remarkable from the circumstance of its containing, with specimens of the unfossiliferous beds of the Lower Purbecks of Portland, abundant fragments of the fossiliferous beds of the Middle Purbecks, none of which now exist *in situ* in the island. In it I also found a number of fragments of the thin seams of fibrous carbonate of lime (known by the quarrymen as "beef"), and of the so-called cinder-bed, which consists of a concreted dark mass of small oysters (so common in the Lulworth and Upway Purbecks), Portland flint, fossil wood, and Tertiary iron sandstone. Mr. Etheridge has kindly determined for me the following species*:—

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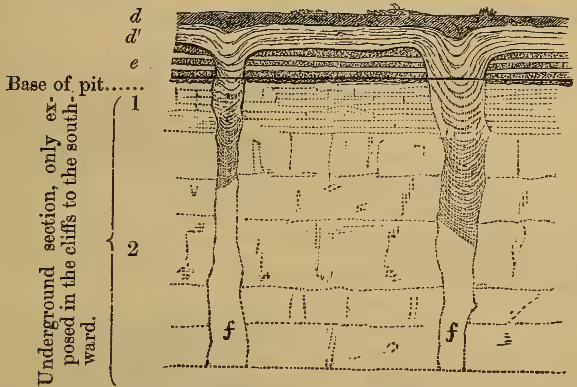
* My friend Mr. Osmond Fisher, who was there with me, considers they may

Cyrene media.
Physa Bristovii.
Hydrobia.
Planorbis.
Cypris striato-punctata.
—— legumen *or* fasciculata.

This mass of débris is angular or subangular, and is little or not at all worn—weathered only. It is not stratified, but roughly spread out with thin intercalated irregular seams of the same loam as *d'*. The loam itself shows traces of rough stratification, and contains thin lenticular seams of the angular débris, indicating the one and the other to be phases of the same phenomenon.

Near where the loam and rubble thin out is another feature which deserves notice. The old beach is here a loose shingle, and has been worked and removed over a considerable extent. This cleared area presents, however, a series of low ridges or walls, running nearly north and south, which have been left by the workmen. On examination these are found to consist of the loam and rubble beds, *d'* and *d*, which have replaced the shingle. The cause of this is not difficult to find. On prolonging these loam-ridges to the edge of the cliff further southward, I invariably found them to correspond with one of the many lines of fissure† by which the island is traversed from

Fig. 5.—*Section showing the longitudinal breaks caused in the old beach by fissures filled by land-materials from above, but open below; Shingle-pit, between section 4 and the landmark.*



1. Purbeck beds. 2. Portland rock. *d.* Soil and dark loam, with angular fragments. *d'.* Loam, laminated. *e.* Raised beach. *f.* Open fissures.

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be referred to Nos. 57, 70, 77, and 82 of his section of Ridgeway (see Damon's Geol. of Weymouth, p. 107).

† These fissures follow the lines of joint, which run within a few degrees on either side of N. and S., and, with the same variation, E. and W. A N.-and-S. fissure will sometimes pass into one E. and W., and afterwards resume its first direction. They are not caused by an outward, or seaward, slip over the Kimmeridge Clay; for the beds dip slightly inwards, or inland, forming a shallow synclinal running N. and S. along the centre of the island. In the above section (fig. 5) the lower part of the débris above *f* is represented too fine: it consists of large and small angular blocks of Purbeck and Portland beds.

south to north, and of which the fissures discovered in digging the Verne moat are an example. These fissures (*f*, fig. 5), which are from 1 to 10 feet wide, are generally open at bottom, while the top has been blocked up with débris of the upper strata, and, in this case, of the beds overlying them also. At Portland Bill blocks of the fissile Purbeck beds have been let down to a greater or lesser depth until stopped by the narrowness of the passage: the shingle bed, *e*, has fallen upon the rock-débris; and the loam bed, *d'*, has followed on the shingle, forming vertical seams which, when the shingle came to be quarried, were left in ridges over the rectilinear fissures, as shown in the preceding section (fig. 5).

None of this angular rubble and loam exists in the centre of the island; but at the northern extremity of Portland there is a remarkable mass of it, though under very different conditions from that at the Bill. The high escarpment which ends abruptly above Chesilton is subtended at its base by a low cliff, which overhangs the southern extremity of the Chesil Bank for a short distance. This cliff, which rises to the height of 60 feet, is composed entirely of angular débris with sand, derived from the Purbeck beds and Portland Stone and Sands, spread out in great lenticular masses, and interstratified with irregular beds of loam, 1 to 4 feet thick, in places having the character of loess (fig. 6). The upper 6 to 10 feet consists almost entirely of broken Portland flint. Scattered through the mass of débris are large angular blocks of Portland Stone and Portland flint or chert, often several tons in weight*. The rough bedding is in general slightly

Fig. 6.—*Old land-débris, with large boulders and seams of Loess, with land shells* (at *s*). Cliff, Chesilton.

K. Kimmeridge Clay. See also A D in fig. 8, p. 47.

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* The following is the measurement in feet of some of these blocks:—9×8½×3½, 10×6×2, 8×7×2, 3×2½×1½ feet. The last is of Portland flint, the others of Portland Stone. Mr. Fisher has since found in it a small block of Sarsen stone (? from the Portland drift).

inclined northwards, but occasionally has a dip southward and westward.

The Kimmeridge Clay (K), which is squeezed up in low ridges in two or three places at the base of the cliff, rises at the south end of it until it is lost under the Portland Sands on the face of the escarpment. Up the slope so formed the angular débris extends to a height of about 200 feet, at which level it gradually thins off, leaving a slight depression or hollow free from the débris, between it and the slope of the escarpment (see woodcut, fig. 8, and Section 5, Pl. I.).

At first sight nothing can seem more unpromising for the discovery of fossils; but I found them in two places, viz. at *s* (fig. 6), and again higher up, at a depth of about 12 feet from the surface and 80 feet above the base of the débris, in a bed of sandy loam underlying a large boulder. At the latter they consisted of the following species:—

1. Bithinia tentaculata, *Müller*: opercula.
2. Planorbis parvus, *Say*, = P. glaber, *Jeffreys*.
3. Limnæa peregra, *Müll.*, var. maritima.
4. Pupa marginata, *Draparnaud*.
5. Candona candida.
6. Cypris Browniana.

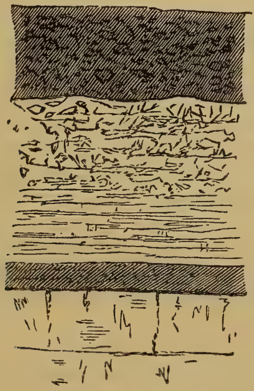
Foraminifera.

In the former, *s*, they occurred in a small intercalated bed of brown loam near the base of the cliff and 50 feet deep in the débris. Here they were very rare, and of only one species,

Pupa marginata—together with one undeterminable leaf-impression?

This angular débris stretches only a short distance inland in the direction of the Verne, and is quite disconnected with the talus (T, fig. 8) formed by the existing cliffs or escarpment. I believe, however, that the broken and disturbed state of the upper 2 to 3 feet of the fissile Purbecks in all the higher parts of the island is part of the same phenomenon. In the small valley passing down by

Fig. 7.—*Section at Sugton Pit near Southwell.*



1. Black earth with weathered fragments of Purbeck strata ... 6 feet.
2. Broken Purbeck in angular fragments, passing downwards into
3. Undisturbed Purbeck beds... } 10 feet.
4. Dirt-bed .... $1\frac{1}{2}$ foot.
5. Portland Stone .... 50 feet.

Southwell this is overlain by another bed, due rather to rain-wash (see fig. 7, p. 39).

At Lulworth and Arish Bay, a local angular drift-deposit of the some age flanks either side of the valley facing the sea.

Other Drift Beds.

The wide undulating tract of the Kimmeridge and Oxford Clays, Coral Rag, and Forest Marble between Portland and the Chalk range is generally perfectly bare. It is only at the following places that I have met with other small beds of drift:—

1. At levels of from 30 to 50 feet on the skirts of the hill between Portland Ferry and Wyke. It is a coarse gravel, composed of subangular Chalk-flints and Greensand chert* with a few pebbles of Portland flint, from 2 to 4 feet thick, and reposing upon a worn and eroded surface of Kimmeridge Clay and Coral Rag (*b''*, see Map and Sect. Pl. I.).

2. Between Melcombe Regis and Furzeland are two low flat hills about 50 and 60 feet high, capped by a peculiar drift-gravel, which is worked on the left of the road turning off to East Chickerel. It consists almost entirely of subangular fragments of chert from the Upper Greensand, imbedded in a red clayey matrix, from 2 to 8 feet thick, sometimes covered with 2 feet of grey clay, and reposing in patches upon a very irregular bed of Oxford Clay. It was only after some search that I found in it a few small subangular chalk flints and a small pebble of white quartz. A similar gravel caps the hill half a mile west of the bridge over the Back-water (*c*, Pl. I.).

3. Traces of a coarse gravel-drift, chiefly of chert, exist on the top of Crook Hill, near West Chickerel; but there is no bed of it.

4. On a hill between Weymouth and Broadway, east of Radipole, and at a height of about 70 feet, is a thin bed of gravel, composed of subangular chalk- and Portland flints, Greensand chert, large Sarsen-stones, and Tertiary flint-pebbles (*c*).

5. A similar gravel caps one of the hills midway between West Chickerel and Portisham.

6. A remnant of a much thicker deposit of gravel exists on the cliff immediately east of Osmington Mill, and again east of Radcliff Point, at the higher level of about 150 feet. It consists almost entirely of a mass of brown subangular chalk-flints, many of them of large size, with a few fragments of Greensand chert, sandstone, and Portland flint, in red clay and sand, 8 feet thick (*b'*).

7. On a still higher level of about 300 feet, and capping the hill on the right hand of the road between Preston and Osmington, a small patch of fine flint and loess drift lies in hollows on the Portland Stone (*b*).

8. Another thick bed of still older gravel, composed chiefly of local Tertiary materials, overlies, and is scarcely separable from, the Tertiary beds at places on the highest points of the Chalk range †.

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* On one fragment was a cast of *Pecten quadricostatus*.

† As I am uncertain of the extent of this bed, I have marked it on the map in one shade with the Tertiary beds, which also consist chiefly of sands and shingle-beds.

It is from 10 to 15 feet thick, and of a red and ochreous colour, but it weathers white. The matrix is a sandy loam and clay. Nine tenths of the gravel consist of well-rolled chalk flints; and the other tenth consists, in the order of their relative abundance, of:—1, large and small white quartz and red quartz pebbles; 2, subangular fragments of Portland flint; 3, chert and ragstone of the Greensand (some of the latter in blocks of considerable size; one was $5\frac{2}{3} \times 2\frac{3}{4} \times 1$ feet); 4, small subangular fragments of red porphyry; 5, jasper; and 6, a few small fragments of worn shelly limestone (Forest Marble?). In places the gravel is much disturbed. The pit from which the above collection was obtained, is within 50 or 60 feet of the summit of Blackdown (790 feet). The gravel is probably of older date even than the mammaliferous drift of Portland, and may belong to some part of the Glacial period.

In none of these beds of gravel could I find either bones or shells; but the remains of the elephant (*Elephas primigenius*?) have been found in a low-level drift (*a*, in Map, Pl. I.) at Radipole, probably that which follows the course of the small stream, and was noticed by Dr. Buckland as being of some extent in the valley near Upway; but no section of it was exposed at the time of my visit. A low-level valley-gravel also occupies the small Abbotsbury valley; and a trail of gravel extends over the hill north of it and on the lower slopes of the Upway valley.

Capping the high chalk ranges of Upton, the White Nore, and Abbotsbury, is a thick bed of perfectly angular sharp chalk-flints in a reddish clay reposing on a deeply indented surface of chalk, while a similar angular drift composed of fragments and masses of chert and ragstone cap the Upper-Greensand hills north of Abbotsbury. It is not, however, my intention to describe this or No. 8 further at present; I merely refer to them as having been the storehouses whence much of the later drift-beds have been supplied.

Calcareous Tufa Deposit.

The raised beach on the east cliff is often cemented by carbonate of lime into a compact conglomerate. It also forms in places detached porous masses of tufa of considerable size, and fills up the interstices of the Purbeck débris. It is newer than the angular débris; for in a section on the cliff near the lower lighthouse the following is the order of superposition:—

Tufa full of recent land-shells	1½ foot.
Brown loam with angular débris	2 feet.
Broken surface of Purbeck, with traces of beach.	

This tufa is apparently due to some springs which still occasionally issue on the slope of the hill a short distance inland from the beach, and which formerly gave off a greater volume of water than at present.

Concluding Remarks.

The study of the chronological relation of these deposits is a subject of much interest. As before mentioned, Portland, with its capping of the fissile beds of the lower Purbecks, presents a bare rock-surface. There is no trace of any more recent Secondary or of any Tertiary strata anywhere in the island; nevertheless the mammaliferous drift of the Admiralty Quarries contains well-worn pebbles of *chert* from the Upper Greensand, and of *iron sandstone and Sarsen-stone*, together with small blocks of the latter from the Tertiary strata, and *chalk-flints* from the hills between Upway and Dorchester, a distance of from eight to ten miles to the north of Portland, from which it is separated by a low plain of older strata, where none of the few scattered drift-beds has any resemblance to the Portland drift. This latter stands alone; and although at a greater distance from the Tertiary strata *in situ*, it contains nevertheless a much larger proportion of their débris than do any of the nearer and lower-level drift-beds.

These Tertiary and Greensand materials could only have been transported to their present position by a floating iceberg or by a running stream. The former is not probable, as the transported rock-specimens are all waterworn and mostly well rounded, and they are associated with mammalian remains and a silt which has the ordinary characters of a freshwater loess, although, as is common with the loess itself, no shells have been found in it. I can only conclude, therefore, that this deposit has been formed by direct transport by a stream running southward from the Greensand and Tertiary area and passing over Portland; and this, necessarily, could only have taken place when the intervening district was bridged over by strata since removed. It follows that the denudation of the plain of Weymouth and the deposition of the several drift-beds found thereon are of more recent date than the mammiliferous drift of Portland (see Sections 1 and 2, Pl. I.).

If the dip of the Portland and Purbeck beds at Portland be prolonged northward, they would reach an elevation of about 1000 feet at Broadway, and of about 1500 feet at the Ridgeway, and thus interpose a high ridge between Portland and the newer strata from which the pebbles of the Portland drift have been derived; consequently either the crest of the anticlinal had then been removed, and a high level plain of the Jurassic strata extended from Portland to the Greensand and Tertiary area, or else at that time the north end of Portland had not been upheaved, and a continuous plain of Portland and Purbeck extended to the Bill of Portland from the point where those formations were brought into contact with the newer strata by the great Ridgeway fault. Looking to the facts that the Portland drift is at a height of 400 feet, or nearly that of the supplying Greensand and Tertiary strata—that the Portland plateau is prolonged northward to 100 feet higher, and is then abruptly truncated—and that the drift-bed, although rich in Tertiary sandstone, does not contain a fragment of the Coral Rag, Forest Marble, or other rocks which, under the first-named conditions, must have formed the surface of the plain over which the stream would have passed, it is, I think, more probable that the second condition, or that of a gradually sloping plain of Portland and Purbecks extending from the Bill of Portland to the Greensand

and Tertiary area, obtained at the period of the Portland Drift (see Section 3, Pl. I.).

The disturbance which raised the Weymouth district and elevated the north of Portland, is the central anticlinal of the Jurassic series (A in Map, Pl. I.), which runs east and west and brings up the Forest Marble between Broadway and Buckland Ripers; for I find that on prolonging the angle of rise of the Portland beds northward, and that of the Purbeck beds (where they crop out on the south of the great Ridgeway fault) southward, the two planes meet exactly over the ridge of that line. The great Ridgeway fault is, I believe, of older date.

If I am right in this intepretation, then it is probable that the anticlinal bringing up the strata below the Chalk at Purbeck, and likewise the great upheaval at the back of the Isle of Wight, both of which are on the same line of disturbance as the Broadway anticlinal, are also of the same age; and we thus obtain a marked instance of elevation and denudation during the Quaternary period.

The great difference of level between the mammaliferous drift and the raised beach might lead to the supposition that they were of different ages. Still, as the former is not a case of capping horizontally an isolated hill, but of forming part of a sloping surface continuous from the northern to the southern end of Portland—and as that surface, for the reasons before mentioned, had its inclination given it subsequently to the deposition of the drift, and when consequently its level above the sea may not have exceeded from 100 to 150 feet, or about 50 or 100 feet above that of the old beach, while the old beach itself (like the drift-bed) contains materials derived from the same Tertiary and Greensand area,—it is probable that the drift-bed and the raised beach were contemporaneous. In fact, while in the upper part of the Admiralty Quarries the drift-bed attains a height of 400 feet, at the angle of the road near the new church it is only 346 feet high, still dipping in the direction of the Bill. On the other hand, the Old Beach, which at the Bill is only 24 feet above the present beach, rises gradually northward until near the Sand-holes, where it attains a height of 36 feet. It is probable, therefore, that the old stream emptied itself a short distance off the present Southwell shore into a small bay, of which the land passing from the Sand-holes in the direction of the lower lighthouse formed the western horn.

The Portland raised beach is by far the most interesting one in the south of England, whether for its extent, its thickness, its large exposure, or its general conditions. In the first place, the materials of which it is formed are partly of local, but still more are of distant origin. Although it contains pebbles of Portland Stone and chert, it is essentially a chalk-flint shingle with a considerable proportion of pebbles of chert from the Greensand. It also contains subangular brown-coated flints, derived apparently from an old gravel, with a few which may be referred to Tertiary strata, together with some angular fragments of chalk-flint showing no wear. With these are a number of pebbles of red sandstone and of light-coloured and reddish quartzite derived from the Budleigh-Salterton conglomerates of the New Red Sandstone; while small pebbles of red porphyries from the Heavitree and Dawlish conglomerates are not rare, and with them are a few pebbles of slate, and micaceous sandstone, possibly from Devonian strata, and one large subangular pebble of a reddish granite, perhaps from Cornwall. With the exception of the few angular fragments of flint and the granite pebble, all the above are well-rolled pebbles, such as might be formed on any exposed shore. The only circumstance indicating ice-action is the presence of the two large subangular blocks of sandstone, not of local origin*, in the eastern section of the beach, and the granite pebble in the western. It is evident that the drift of the shingle was then from the westward and Devonshire coast, and that it was carried to and round the then small Portland headland†.

The list of shells from this beach includes many species not before found in any raised beach; but notwithstanding this the list falls very short of the number of species now found on the Dorsetshire coast. In the raised beach there are 28 species, whereas Mr. Damon gives from this coast a list of 240, of which he informs me that about 40 belong to the littoral zone.

With one exception, all the shells are, according to my friend Mr. Jeffreys, of species now living in the British Channel; but I would point out that they are also all species which have a wide northern range —that the *Cyamium minutum* was first found in Greenland, where it abounds—and that there is a marked absence of more southern forms.

The mass of loam and angular débris overlying the Raised Beach is not only newer than the beach, but is also subsequent to the anticlinal which raised the north end of Portland; for at the foot of the present high escarpment originating in that elevation, is a still larger accumulation of this débris. Whether or not this deposit is newer than the other drift-beds with which the raised and denuded Weymouth area is dotted, there is here no direct evidence to prove; but I take it next in order, in consequence of its connexion with Portland and with the Raised Beach.

Similar deposits overlying other raised beaches have often been described, and have generally been considered to be a "head" or talus of subaerial origin. Mr. Godwin-Austen‡, who has very carefully examined into their structure, range, and origin, both on the English

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* If not transported by coast-ice, they may have been driven down by the stream or floated by river-ice.

† It follows from this that it is not necessary to assign a directly distant origin to any of the pebbles of the Chesil Bank, as those from the Devonshire strata are due rather to a transport which took place during the Quaternary period, when the land between the distant headlands on which raised beaches have been found, such as Berry Head, Start Point, Hope's Nose, and Portland, had not been indented by the deep bay now sweeping round by Sidmouth, Lyme Regis, and Bridport. No doubt the coast-line at that period took a straighter course from Hope's Nose to the Bill of Portland. This, however, is a subject which I purpose to discuss elsewhere (Inst. Civ. Eng.), as it bears upon questions connected with the present set of the currents and tides, and on the origin of the Fleet.

‡ "On the Superficial Accumulations of the coasts of the English Channel, and the changes they indicate," Quart. Journ. Geol. Soc. vol. vii. p. 118, 1851.

coast, in the Channel Islands, and on the coast of Cotentin, says of them:—"These beds, wherever found, are remarkably uniform in their general appearance and composition: they consist of fine earthy matter, such as would result from the decomposition of the rocks of the place; mixed with this are fragments of rocks of all sizes, ranging up to blocks of considerable dimensions: the fragments are obviously smaller in the upper portion of these accumulations than in the lower. In places where the slope of the land is at a small angle, the "head" is mostly earthy, and of small amount; where it is steep, or rocky, it becomes in proportion thick and fragmentary: the component fragments will, in this case, be seen to have been derived in every instance from the masses of rock immediately overhanging—*the materials are always strictly local as to origin.*

"These accumulations, as seen in cliff-sections and at short distances, present an appearance of horizontal arrangement; closer examination, however, shows that this has nothing of the character of subaqueous arrangement: another very obvious feature is, that *the fragments are all perfectly sharp and angular*—no specimens of included waterworn rock are ever found." After a general survey of the whole area, Mr. Godwin-Austen concludes that they are of subaerial origin, and are due to the action of great cold—not necessarily that of a glacial period, but arising from elevation of the land; and he thus tersely sums up:—"These phenomena so exactly accord with what is to be observed in all regions of excessive temperatures, whether resulting from geographical position or from altitude, they are so totally beyond the power of any present agencies, that it seems absolutely necessary to call in the operation of cold to adequately account for them. Many considerations oppose the possibility of low temperature along the parallel of 50° N.E., whence these observations have been derived; and the only physical condition which I can imagine sufficient to account for the fragmentary detritus generally of the whole of those areas from which I have borrowed illustrations, is that of *an elevation of great amount, such as would place the whole of the higher portions of this country in regions of excessive cold.*"

At about the same period I described a similar deposit at Sangatte Cliff[*] much in the same terms as regards its composition as Mr. Godwin-Austen, but came to the conclusion, after examining this and also the Brighton bed, that the acting force had been subaqueous rather than subaerial, and that it was of short duration and violent; but I did not then venture to speculate on the causes which led to the result or the exact mode of operation.

At that time neither Mr. Godwin-Austen nor I had detected any shells in these beds. I subsequently[†] found land-shells of the most delicate structure in the Sangatte deposit.

While in the main I agree with my friend as to the condition of the débris, I do not agree with him on some points of structure. So

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[*] "On the Drift at Sangatte Cliff, near Calais." Quart. Journ. Geol. Soc. vol. vii. p. 274, 1851.

[†] Quart. Journ. Geol. Soc. vol. xxi. p. 440, 1865.

far from the larger fragments being at bottom, my experience leads me to a different conclusion. At Sangatte I found the lower part of the deposit to consist of a chalk rubble, often very fine, and the upper part chiefly of fragments of flints of all sizes. At Brighton, seams of chalk silt are intercalated in the mass from top to bottom; whilst at Chesilton the section distinctly shows a large preponderance of heavy blocks of Portland flint and stone in the upper part of the cliff. There was not a single large block of stone or flint within reach in the lower part of the cliff; and again at the Bill the superposition of the coarse angular débris on the fine loam and silt is clear.

Nor can I agree with those who consider this deposit an old talus, or with Mr. Godwin-Austen, who regards it as a talus formed at high altitudes under great cold; for in either case the materials would, as pointed out by the latter, have arranged themselves at the angle taken by loose materials falling over steep slopes; and when, at first, the cliffs or slopes were steepest, the greater would be the masses which would fall from them, while with diminishing slopes or angles, the rubble or débris would, as a rule, become of smaller size and of diminished quantity. Also if the deposit were a mere subaerial accumulation, it would in all cases be in close connexion with the slope or cliff supplying the materials —would dip from it at a high angle, and never be carried far beyond the range which that angle would subtend; whereas at Sangatte and at Brighton, although the layers of the deposit are turned up at a high angle against the old cliff, they are prolonged in a gradually diminishing angle to a considerable distance from it. At Chesilton the deposit does not even extend up to that part of the cliff where the Portland Stone is *in situ*; and whereas the escarpment is 400 feet high, the angular débris, commencing at the height of about 180 feet (see sketch, fig. 8; Sect. 5, Pl. I.), is prolonged to a distance from it of 1600 feet, or very far beyond that to which any materials falling from the cliff, had it even been originally double the height, could possibly have extended. The recent talus and old débris are in fact perfectly distinct. In the case of this deposit at the Bill of Portland, these features are still more decided. At the base of it is a light loam foreign to the old cliff against which it abuts, while the strata forming the top of the cliff are broken up and thrown over this loam, and the two together extend southward over the raised beach at the slight angle of 4° or 5° for a distance of nearly a quarter of a mile. The old cliff itself, and the surface of the old land above the cliff and of the old shore, are all levelled, and form a uniform and scarcely apparent slope, their original relation and levels being completely obliterated (see fig. 4, Pl. I.)

I hold that small angles such as these and such a mode of arrangement are quite incompatible with any subaerial deposit of local origin formed on the principle of a talus; and the difficulty becomes greater when we see that in this bed at the Bill there are fragments of strata which not only are absent in the adjacent cliffs, but do not even at present exist on the island. Not only is the fall insufficient to carry the materials to the distance shown, but there is evidence of a *vis*

Fig. 8.—*View, looking south, of Chesilton Cliff, composed of Angular Débris (Land-wash), and of the Escarpment of Portland Stone with the Talus now forming.*

P. Portland Stone. P S. Portland Sands. KI. Kimmeridge Clay. A D. Angular débris. S. Shells in loam. T. Present talus.

a tergo propelling forward the débris beyond and out of reach of any overhanging cliff.

We may, I think, consider that the following points are now established:—

1. That the débris is entirely angular, and is composed, if not altogether of local materials, at all events of such as come within the area of drainage.
2. That the finer material is more frequently found in largest proportion at the base of the deposit, but that it recurs irregularly all through the mass of the deposit from bottom to top.
3. That the deposit has a rough stratification caused by the intercalation of irregular lenticular masses of fine and coarse portions, the whole having a prolonged and gradually decreasing slope seaward at angles far smaller than could possibly be taken by materials falling over any cliff or a sloping escarpment.
4. That it is thickest at the base of valleys or of cliffs where they debouch on the coast-line.
5. That it contains the bones of land animals, together with land and freshwater shells.

These points afford definite grounds for speculation. The materials are evidently of origin which, if not altogether local, never extends beyond the drainage-area of the spot; and it is equally clear from their arrangement and the distance they subtend the cliff, that no mere subaerial action of weathering could have produced such a deposit. Nor can I conceive the presence in any subaerial talus of delicate land shells and of detached and broken bones of land animals; for the former are of species which would not frequent dry and stony surfaces, while the skeletons of any of those which might happen to have been destroyed by a fall, would hardly have their parts so dispersed and reduced to so fragmentary state as we find here. On the supposition of Mr. Godwin-Austen that the degradation of the surface took place at a high altitude in regions of excessive cold, we might obtain a greater propulsive power by the action of snow or ice; but still I doubt whether it would be sufficient to give rise to the prolonged slopes we have noticed, while the presence of land and freshwater shells, of bones of the horse, elephant, rhinoceros, &c. in some places, seems irreconcilable with such conditions of land.

On the other hand it is evident that we have in this deposit a surface-wash composed of the loose débris of the rocks of the vicinity, of the shells and slugs of a land surface, and of the remains of animals which might have frequented the same.

It seems to me that the results may be ascribed to one of three causes. Either, first, a mass of ice passing over the surface of the land may have pushed forward the débris and thrown it seaward down valleys and over cliffs, turning over their edges; or, secondly, the accumulations of winter snow may, on sloping surfaces, have tended in a lesser degree to the same result; or, thirdly, the transient passage of a body of water may have swept the land-débris down to the shore-line and to a certain distance beyond. With regard to the action of ice, I feel about it the difficulty before expressed on the score of the presence of organic remains; and also, although a local mass of ice might have radiated from the central higher ground southward toward the Bill, and in a north-westerly direction at the other end of the island, the size of Portland and its height are too limited for local glaciers, while if it formed part of a continental ice-sheet it would have a more definite and uniform direction, and we should expect to find on the adjacent mainland traces of that ice-sheet, which we do not.

The limited size of the island forms also a similar but not so strong objection to the operation of accumulated snow.

I find in the third alternative an explanation which agrees with the observed conditions. Sir R. I. Murchison, with respect to the Brighton Cliff, and myself with respect to the Sangatte Cliff, had, so far back as 1851, arrived independently at somewhat similar conclusions regarding the condition under which they were formed, save only that his generalizations were more extreme, attributing to one operation what I should attribute to several. He supposed that the angular débris resulted from an extended catastrophe* caused by great waves produced by great oscillations and violent fractures of the crust of the earth, "by which the earth's surface has been so powerfully affected in former times," passing over the land, and by "the large area under consideration being suddenly broken up and submerged." I then limited my conclusions to the fact† that the accumulation of the Sangatte drift was tumultuous and of short duration, and that it was formed under water.

At present none of the Middle Purbecks have been discovered *in situ* in Portland‡; nevertheless we have shown that fragments of them abound in the angular débris at the Bill. Either these have been derived from the mainland or from beds which formerly existed on the island. Had it not been for the circumstance that the angular débris is found on the level of the Kimmeridge Clay at the base of the escarpment at the north of the island, as well as on the level of the Lower Purbeck on the south, I might have hesitated in ascribing to it a local origin, and considered that it more probably came from the beds *in situ* on the mainland before the elevation of the anticlinal line and subsequent denudation. There are, however, two objections to that view—viz. an absence of specimens derived from any other strata within that area, and the earlier date of the denudation. I therefore imagine that the fragments are of local or Portland origin, that prior to the accumulation of the angular débris the Purbeck series in Portland was more complete, and that, instead of being confined, as now, to part of the lower almost unfossiliferous beds, it

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* Quart. Journ. Geol. Soc. vol. vii. p. 389.

† *Ibid.* p. 274.

‡ On the slope, north of the lower lighthouse, I found in a small old quarry a thin seam of stone full of *Cyprides*, but of the smooth Lower-Purbeck variety. I failed to find on the rather higher ground above any section to show what the strata were. At Blacknore the thickness of the Lower Purbeck is very considerable, but fossils are absent or very scarce.

included in some part of the island the lower beds of the Middle Series, of which both the fossils and lithological fragments are so abundant at the Bill. The iron-sandstone grit and the fragments of Sarsen-stone of Tertiary age may be derived indirectly from the drift bed of the Admiralty Quarries, which then also was, no doubt, of greater extent.

I therefore infer that, probably in consequence of some major disturbance at a distance, the Isle of Portland, together with the whole line of coast from the Land's End to the Straits of Dover, as well as the opposite coast of France, was gradually submerged, and that the sea, the boundaries of which are marked by the raised beaches on both coasts, encroached upon the adjacent land; that this submergence was only temporary; that the emergence, at first gradual, was marked by short oscillations, which, according to their relative force and duration, swept down the soil with its land shells and softer beds, alternately with the coarser materials and the bones of animals drowned by the inundation, spreading first one and then the other in irregular beds and lenticular masses; while the final emergence, more sudden and consequently of greater effect, swept down the overlying coarser débris. By such agency, I conceive, were the Middle Purbecks denuded and swept seaward to the Bill of Portland; while at Chesilton the coarse débris with the large blocks of chert and stone were transported in another direction, large and small together, and spread out far beyond the foot of the immediate escarpment.

Or, again, it is possible that a succession of waves caused by earthquake-movements may have swept at short intervals over the adjacent land. In any case, as the "angular débris" comes down to the sea-level at Chesilton, again at Sangatte, and elsewhere, I think it clear that, whatever the disturbance, one effect was to raise suddenly the old beaches which fringed the then coast to their present height above sea-level.

A review of the extent of the submergence is beyond the limits of the present paper; but from the fact that at Chesilton the great mass of the débris and the large blocks of Portland flint come from beds now from 350 to 450 feet above the sea in that part of the island, and from their great size and the force necessary to remove them, we may assume not only that the highest summit of Portland was submerged, but also that there must have been above it a column of water of some height and power.

Such a comparatively sudden change of the relative level of land and sea could not have been effected without great disturbance; and we have some evidence of that in the partly open fissures by which Portland is traversed, and especially by those near the Bill, where I have shown that, after the formation of the old Raised Beach, rents were formed in that beach and in the subjacent rocks, into which the more recent loam and angular débris must have been let down while apparently in a semifluid state or under water.

Of the relative age of the old "Land-wash" (which is the name I would suggest for this deposit), and of the several small drift beds in the neighbourhood of Weymouth, the evidence is not very clear. Judging from the levels of these beds, they may probably be referred to different periods, extending from one shortly subsequent to the elevation of the anticlinal axis, to the one when the streams had obtained their present position and present level. Thus the small patch capping the hill beyond Preston may be the oldest (*b*″); the patch between Chickerel and Portisham, and those on the hills near Osmington Mills, and which consist chiefly of large chalk-flints, may be the next (*b*′); those above Radipole and the Portland Ferry, third; while that in which the remains of the mammoth have been found is confined to the low-level beds of Radipole and is the last (*a*).

But the most anomalous mass is that between Weymouth and Chickerel. It is composed, as before observed, almost entirely of subangular fragments of Greensand chert. The lie of the land, which intercepts communication with the Abbotsbury hills, and the presence of the more composite drift both to the north and south, lead me to suppose that this Greensand drift may have been derived rather from the district of the White Nore before the excavation of Weymouth Bay than from that of Abbotsbury; but I must leave this question open. It does not seem connected with any river-gravel. The drift between Wyke and the Ferry, where we get Greensand chert, chalk-flints, and Portland chert mixed, may possibly be assigned to the same age.

On the other hand, regarding the drift in the Upway valley and at Radipole as a low-level valley gravel, that on the hill east of Radipole, which contains an abundance of Tertiary débris together with chalk-flints brought down from the hills at the head of the Upway valley, may be a high-level gravel of the same river-system.

Such, briefly, appear to be the very remarkable series of phenomena which, at a comparatively recent geological time, have given form and shape to the district round Weymouth. Carrying our view back to the latter part of the Glacial Period, before the present valley-systems or even some of our plains were elaborated, a broad tract of Chalk, bounded in places by Greensand, and capped by Tertiary beds and older gravels, rose inland; and with these the Purbeck and Portland beds were brought into level juxtaposition by and along the great line of fault running westward and eastward nearly midway between Dorchester and Weymouth. From that district the surface of the country sloped gradually to the south end of Portland; and over this surface, which then bridged over the plain of Weymouth, streams, originating in the Chalk, Greensand, and Tertiary district, flowed southward to the Channel. It was one of these streams which, passing over Portland, rolled down to that island pebbles derived from those several newer formations, while the floods and ice of winter carried down the larger Sarsen-stone boulders also so common in the same fluviatile bed, and entombed the remains of the elephant, horse, &c., then living in that area.

At this time the line of coast extended, much as it does now, but with fewer and deeper bays, from the shores of Cornwall, passing close to Plymouth, touching the headlands of Berry Head, Start Point, and

Hope's Nose near Torquay, and then taking a nearly direct line across Bridport Bay to the south end of Portland. Thence, at some distance beyond, it passed more inland, ranging near Fareham and Chichester, to Brighton, and to the Straits of Dover. Up this channel the shingle was drifted, as to a certain extent at present, from the westward, while floating ice transported the larger blocks found in places on the Sussex coast from more distant localities.

In the mean time an east and west anticlinal disturbance slowly elevated the Weymouth district, and with it part of the Purbeck and Portland area—succeeded or accompanied by a denudation which not only levelled but deeply channelled the uplifted areas. At the close of this period Portland must have presented nearly the same features as at present, only that the surface was varied by the presence of hills of the Middle Purbeck strata. The final submergence of which we have before spoken, and the subsequent emergence, buried the old cliff and sea-line under the mass of angular débris washed down from the adjacent land (denuding possibly some areas more deeply), and left the district much as we now see it, with its pleasant variety of hill and dale, its well-marked and bold escarpments, and its diversified geological features.

Note on the Fossil Shells. By J. Gwyn Jeffreys, Esq., F.R.S.

I have examined the shells and washed shell-sand from the raised beach at Portland, collected by Mr. Prestwich. The shells are rather northern than southern; but but I have not detected any peculiarly arctic species, and certainly none of a Mediterranean or Lusitanian type. All the species inhabit the British coasts from Shetland to Yorkshire, except one, which I consider undescribed, and propose to name *Rissoa subcylindrata*. I subjoin a description of this species. Another species (*Trochus helicinus*) has not, so far as I am aware, been found south of Yorkshire and Dublin Bay. The most northern known locality for another species (*Trochus umbilicatus*) is Stornoway in the outer Hebrides; and it occurs in a raised beach at Portrush*.

The freshwater bed which overlies the raised beach contains very few species of Mollusca. These shells I am disposed to regard as northern, although the species have an extensive distribution southwards.

J. Gwyn Jeffreys.

Ware Priory,
9th June, 1874.

Rissoa subcylindrata, Jeffreys.

Shell somewhat cylindrical, solid, opaque, glossy: *sculpture* none, except occasional lines of growth: *colour* whitish: *spire* rather short; apex blunt: *whorls* 4–5, convex, regularly increasing; the last

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* All the shells belong to the littoral zone. The sand and its contents appear to have formed part of a beach or strand in the neighbourhood of rocks.

occupies two thirds of the spire when viewed mouth upwards: *suture* deep: *mouth* more round than oval, effuse at the base: *outer lip* thin: *inner lip* reflected; behind it is a small but distinct umbilical chink.

L. 0·075; B. 0·05 inch.

Its nearest ally is *R. parva*, var. *interrupta*, from which, as well as from the other varieties of that common species, the present differs in its cylindrical shape, bluntly pointed spire, and the absence of coloured markings. It somewhat resembles a dwarf *Hydrobia Ferussina*.

EXPLANATION OF PLATE I.

Fig. 1. Outline section from Portland to Dorchester, showing the outline of the anticlinal. True scale.

2. The same section from Portland Bill to Dorchester. Horizontal scale 1 inch to 1 mile; vertical scale 1 inch to 1000 feet.

3. Restored section on the same line before the elevation of the anticlinal. Scale as in fig. 2.

4. Section of the Raised Beach at Portland Bill, west side. True scale.

5. Section of Old Angular Land-débris at Chesilton. True scale.

6. Map of Portland Bill and the adjacent parts of Dorsetshire. Scale $\frac{3}{8}$ inch to 1 mile.

Discussion.

Rev. O. Fisher remarked on the polished pebbles exhibited, from the summit of the Isle of Portland. Tusk of Elephant and remains of *Bos longifrons*, with a sling-stone, were found on a ledge in a fissure, which was blocked at one end by a talus of fine materials from the surface, with land shells. The polish on the pebbles was produced by water containing mud filtering through them, and passing below into a fissure caused by the slipping of the stone on the clay.

Mr. Topley considered that the disturbance described was of comparatively recent date; but he was scarcely prepared to admit that it was as low down in the Drift Period as the author supposed.

Prof. Hughes thought that the whole question turned upon the original configuration of the country—what was the line of the old channel in the old river-valley now forming the English Channel.

Prof. Ramsay remarked that many questions were raised by this paper. In the anticlinal of the Weald the Cretaceous strata are accidentally conformable, whilst more to the west the Oolites are unconformable to the Cretaceous. The mass of the Eocene passed over the anticlinals of the Portland district; and what had become of the overlying mass? He thought that it had probably been removed by subaërial influences.

Mr. Koch referred to the polishing of stones in river-beds, which he had noticed in the north of Spain, in Bohemia, and in the Jura, and stated that in river-beds carbonate of lime is deposited on the stones and preserves their polish.

Mr. Godwin-Austen said that to whatever period the east and west disturbances might be assigned, they were evidently comparatively recent. The phenomena shown in the section described by Mr. Prestwich corresponded with what might be observed in modern beaches. The angular gravels might be due to glacial action.

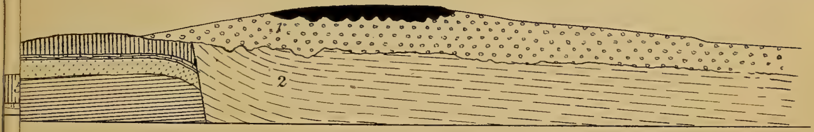
Mr. Gwyn Jeffreys stated that the first shell-sand sent to him by Mr. Prestwich from the raised beach contained species identical with those now living on that coast; but the second collection gave species not found nearer than Scarborough and Dublin. He referred to the abundance of *Cyamium minutum*, a Greenland species which also inhabits the coasts of New England, is rare in the south of England, but very common in Scotland. He regarded the raised sea-beach as of the same character as the existing sea-beaches in Shetland: the species were essentially northern; and no Mediterranean forms were met with. In the Selsea raised beach the species are southern.

Mr. Prestwich, in reply, stated that the fissures referred to by Mr. Fisher are comparatively recent, and that probably the specimen of Elephant referred to by Mr. Fisher had been wrongly referred to that locality. In the collection from the fissures at the Verne he had seen no Elephant-remains, but only those he had mentioned in the paper.

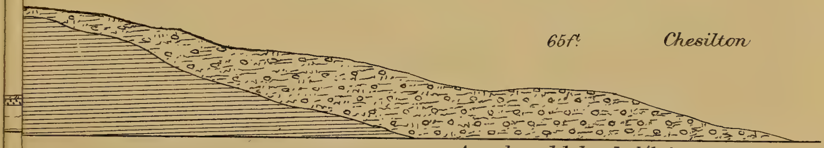
Quart. Journ. Geol. Soc. Vol. XXXI. Pl. I.

2 Chalk. *1 Tertiary beds and Old Gravel.*

FORE THE DENUDATION OF B.



LAND-DÉBRIS AT CHESILTON. TRUE SCALE.



Angular old land-débris with land shells.

Mintern Bros. lith.

Fig. 6. MAP OF PORTLAND BILL AND THE ADJACENT PARTS OF DORSETSHIRE.

Fig. 1. OUTLINE SECTION FROM PORTLAND TO DORCHESTER. TRUE SCALE

Fig. 2. SECTION FROM PORTLAND BILL TO DORCHESTER.
HOR. SCALE 1 INCH–1 MILE. VERT^L 1 INCH–1000 FEET

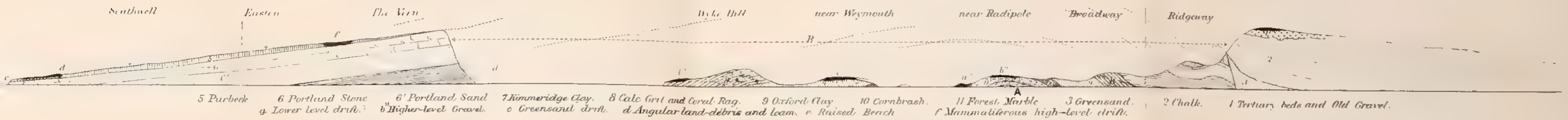


Fig. 3. RESTORED SECTION OF THE ABOVE BEFORE THE ELEVATION OF THE ANTICLINAL A AT AN EARLY QUATERNARY PERIOD BEFORE THE DENUDATION OF B.

Fig. 4. SECTION OF THE RAISED BEACH AT PORTLAND BILL, WEST SIDE. TRUE SCALE.

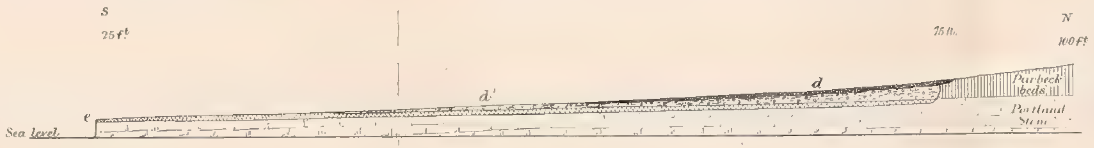
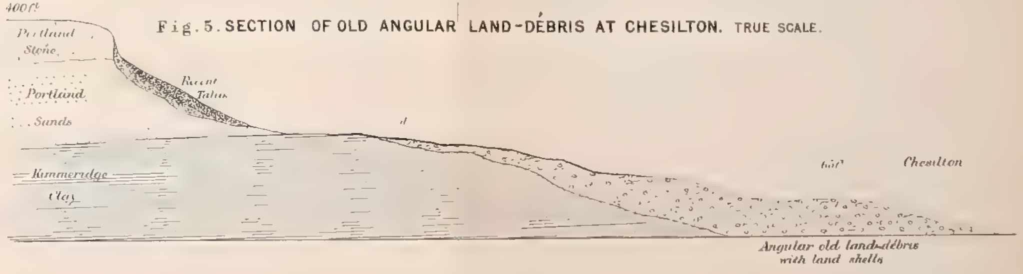


Fig. 5. SECTION OF OLD ANGULAR LAND-DÉBRIS AT CHESILTON. TRUE SCALE.



Mintern Bros. lith.

3. *The* Glacial Phenomena *of the* Eden Valley *and the* Western Part *of the* Yorkshire-Dale District. By J. G. Goodchild, Esq., of the Geological Survey of England and Wales. (Read June 24, 1874.)

(Communicated by H. W. Bristow, Esq., F.R.S., with the permission of Prof. Ramsay, F.R.S., Director-General of the Geological Survey of the United Kingdom.)

[Plate II.]

In the following paper it is proposed to take up the investigation of the North-Anglian glacial phenomena in the district north of that treated of by Mr. Tiddeman in his paper on the Evidence for the Ice Sheet in North Lancashire, &c.*, to carry on the observations northward among the Carboniferous dales on the eastern side of the Lake district, and to endeavour as far as possible to throw some light upon the glacial phenomena of the Eden valley.

Most of the facts were obtained in the course of the Geological Survey of the district by Professor Hughes and the writer, and are given here with the permission of the Director-General. Those relating to much of the Eden valley, properly so called, were collected by the writer in his holiday rambles in 1873–4, and are introduced here to supplement the more detailed observations that have been made on the part of the district hitherto mapped by the Survey.

The Ice Sheet, and Boulder-transportal.

The physical features of the district need not be described in detail, as the accompanying map (Plate II.) will give a better idea of them than could be gathered from many pages of description. There are, however, a few points to which it is desirable that attention should be called, in order that the following remarks may be the better understood.

Generally speaking, we may say that the greater part of the high ground of which Ingleborough, Whernside, and Gragreth form parts lies to the E.S.E. of a line joining Kirkby Lonsdale and a point a little to the north of Kirkby Stephen. The highest fells in this area range from about 2200 feet to 2400 feet above the sea. Most of the principal elevations lie within a few miles of the N.N.E. line just mentioned: to the E.S.E. of this area of highest ground the uplands gradually decline to the level of the plain of York. To the south it is well defined by the line of the Craven faults; and it will be convenient to take the strip of comparatively low ground known as Stainmoor as its northern boundary. Within these boundaries the uplands are much cut into by dales, of which the two principal are Wensleydale and Swaledale. The whole of this area is generally spoken of as the Dale district; it will therefore be convenient to use that name when referring to it further on.

Lying to the north-west of the Dale district is another great up-

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* Quart. Journ. Geol. Soc. vol. xxviii. p. 471 (1872).

land tract, the summits of which range up to nearly 2900 feet. As in the case of the Dale district, the plane of the fell-tops of this area gradually slopes to the east, and passes into the low country of the Durham Coal-measures and Magnesian Limestone. To the south-west this area is limited by the north-westerly Pennine Faults, which range, roughly speaking, from Brough, in the north-east corner of Westmoreland, to Brampton, not far to the north-east of Carlisle. Between the lines of disturbance and the tops of the highest fells the ground rises very rapidly, forming a bold escarpment that in one place rises more than 2000 feet above the adjoining low ground of the Eden valley. Cross Fell, the highest point, is 2892 feet above the sea; and as this Fell necessarily forms a prominent object many miles around, it will be well to speak of the escarpment that it forms part of as the Cross-Fell escarpment, and to call the great tract of moory uplands to the north-east and south-east of it the Cross-Fell district.

A tract of low ground, having but few points in it above 1000 feet, and the greater part below 500 feet above the sea, extends from the foot of the Cross-Fell escarpment to the north-eastern limit of the Lake district. It is more of the nature of a plain gently inclined towards the Pennine escarpment than of a valley, properly so called; but from the circumstance that the river Eden flows through it, it has come to be generally known as the Eden valley.

Westward from the Dale district lies the flattened dome-shaped mass of the Lake country, which is too well known to need any description here. Part of this area is prolonged as a kind of geographical outlier to the east of the depression that the river Lune flows in up to the line of the north-easterly faults; and the generally easterly line of watershedding of most of the Lake-district streams is extended through this all but detached area of Silurian rocks, across the Great Faults, to Wilbert Fell, and thence between the head-waters of the rivers Lune and Eden, crossing the principal water-shedding line of Northern England, to the line of high ground between Wensleydale and Swaledale.

It will be well here to make a few remarks upon the lithological character of the rocks within the area now being treated of, so that the evidence for the direction of flow of the boulder-transporting agent may be rendered clearer.

Beginning south of the northernmost of the Craven faults, between Ingleton and Leck, we find an outlier of Permian rocks lying upon the Carboniferous beds on the downthrown side of the fault. Amongst these Permians a breccia of a marked lithological character occurs; and a similar rock is nowhere to be found anywhere in place to the north of the Craven fault nearer than the Eden valley. A few miles to the east of this Permian outlier the streams that flow southward from the uplands about Ingleborough, Whernside, and Penyghent have cut down through the Carboniferous rocks into the older Silurians that form the floor whereon the newer beds rest. The Silurian rocks differ greatly in lithological character from the Carboniferous beds, so that fragments of the two kinds of rock are easily distinguishable in any section of drift where they may happen to be intermingled.

The Silurian inliers extend only about two or, at the most, three miles into the Dale district. Northward from that the Dale rocks are wholly Carboniferous, and generally speaking may be said to consist of:—a lower series of limestones, sandstones, and shales, the last predominating over a large part of the area that this paper refers to; and an upper series, which commonly occupies the higher ground, and consists of alternations of grits, sandstones, and shales. Occasional thin limestones are found in part of the area, but they are usually distinguishable in lithological character from the thicker limestones of the lower group. Except that in one part of the Dale district there are a few veins of silicified limestone of acharacter sufficiently well marked to allow them to be used as tests of the way that the drift moved, but few rocks are found of such a character that one may identify fragments of them amongst the drift derived from other rocks in the neighbourhood. Fortunately, however, the highest thick limestone of the Yoredale rocks is so much unlike any of the beds above it that it may be safely used to determine this point.

Along the western border of the Dale district the case is far otherwise. The long line of faults joining the Craven- and Cross-Fell branches of the Pennine faults may be said, for more than half its length, to mark off the Silurian area from that occupied by the Carboniferous rocks.

Northward from Leck to near Sedbergh the Carboniferous rocks abut directly against the Silurians; but beyond this, strips and patches of the red conglomerates of the Upper Old Red, and occasional strips of the peculiar apple-green quartz conglomerates of the Lower Limestone Shale, appear at intervals among the faults to a point about two miles south of Rawtha bridge. Both of these rocks are quite unlike either the Silurian or the Carboniferous rocks that they are faulted amongst; they may therefore in most cases be relied upon as tests.

Just to the north of the inliers of Upper Old Red and Lower Limestone Shale alluded to, bosses of diorite come in the Lower Silurian rocks near the faults. Portions of it are of a well-marked character, and can easily be identified amongst drift stones from any of the rocks around.

Passing onwards to the Eden valley, we come upon the peculiar deposit that is locally known as "Brockram." This is a breccia, or a series of breccias, of fragments of Carboniferous rocks, mostly of limestone, in a red sandy matrix, forming a rock of great durability, that comes to the surface as a strip varying in width from 1 to 3 miles. In no instance known does the Brockram in the Eden valley lie higher than 700 feet above the sea; most of it lies between the 500- and 600-foot contours. Its principal areas of outcrop lie to the south of Kirkby Stephen, and near Appleby, to the north of which the rock is generally less compact and durable, and in large masses is distinguishable from that which occurs in the typical areas. A few exposures of Brockram occur at intervals in the low ground skirting the foot of Stainmoor round to Brough; but, as before stated, none of these lies higher than about 650 feet above the sea.

Along the Cross-Fell escarpment there are only two rocks of any value for our present purpose. One of these is the Whin Sill, a bed of basalt that occurs among the Carboniferous rocks in the escarpment, but does not extend further than about five or six miles to the north-west of Brough. The other rock alluded to is the conglomerate that is elsewhere described as part of the Roman-Fell series *. Neither the Whin Sill nor the conglomerate affords a very satisfactory test. Much of the Whin so closely resembles some of the igneous rocks associated with the Silurians of the Lake district that it is often difficult to distinguish between them in cases where fragments of both have got mixed together in the drift. Parts of the Whin, however, may be recognized by those who have seen much of it in place. The finer parts of the conglomerate are so much like the Millstone Grit that they cannot always be relied upon as a test; but the coarser parts, especially where accompanied by the usual matrix, are of more value, and may be traced in the drift a long way from the parent rock. Bearing in mind the occasional uncertainty of any identification of drift fragments of the rocks just mentioned, they have only been made use of for the purpose of proving which way the drift has moved in cases where the fragments are not to be mistaken.

Turning now to the Silurian areas south of the Eden valley, we do not find any very marked types of lithological character in the Howgill Fells; or, if they exist, the writer is not well enough acquainted with them to be able to trace them far from the parent masses. The same remark also applies to the Silurian areas between the river Lune and the point where the oft-described Shap Granite comes to light. Now that this beautiful granite is being so extensively used for ornamental purposes it is needless to give any description of it here, as all geologists who have taken an interest in the glacial phenomena of Northern England must have acquired more or less familiarity with its appearance long ago.

Between Shap Fells and Ullswater the rocks belong to the so-called "green-slate-and-porphyry" series, and have not in any instance been made use of for the purpose that this part of the paper treats of, because of the writer's imperfect acquaintance with them.

Westward from Ullswater a great variety of igneous rocks of well-marked lithological characters come among the Silurians on the north side of the Lake-district watershed. Most of these have been referred to by Mr. Ward, in his paper on the Glaciation of the Northern Part of the Lake-district †. The writer's acquaintance with some of these rocks is partly due to Mr. Ward's identification of fragments from the drift, and partly to the information gained by several days' hammering over some of them in place, especially those that occur in the Caldbeck Fells.

The igneous rocks alluded to, that have mostly been relied upon

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* Quart. Journ. Geol. Soc. vol. xxx. p. 398 (1874).

† *Ibid.* vol. xxix. p. 422 (1873).

in making out which way the drifts of the Eden valley have been moved, are the syenites of St. John's Vale (near Keswick), of Carrock Fell, and of Buttermere, the porphyries of Berrier Nittles and of High Pike in the Caldbeck Fells, the granites of the Calda and Brandy Gill, and the peculiar porphyritic dyke of Armboth Fell and the Helvellyn. Other Lake-country rocks that the writer has not had opportunity of examining in place are not taken into account here, especially as those just named do well enough for the purpose in view.

Turning next to the subject of the glacial markings and the course taken by the ice, it will be well to begin at that part of the Dale district that lies immediately to the north of the Craven fault. Mr. Tiddeman has already alluded to part of this in his paper before mentioned; it is referred to again in this place because a little additional evidence has been obtained since his paper was written. Most of this part of the Dale district was mapped by Professor Hughes, who has allowed the writer to make the fullest use of any information relating to the glacial phenomena of the district.

Mr. Tiddeman has demonstrated that the drift-transportal and the rock-grooving of the country a long way to the south of the Craven faults, on the west side of the Pennine watershed, were effected by a thick sheet of land-ice, which must have come from the country somewhere to the north of the Craven fault; and the object of this part of the present communication is to point out the line of departure whence this branch of the great ice-sheet started.

No fragments of the Brockram, which is mentioned above as occurring to the south of the Craven fault, between Leck and Ingleton, have ever been found to the north of its present area, although pieces of it are found in the drifts that occur to the south-east of it, and probably also in those that lie to the south.

The Silurian areas of Chapel-le-Dale, Crummack, and Horton-in-Ribblesdale have yielded no boulders that have travelled to the north. The rocks themselves are quite unlike the overlying Carboniferous beds; if, therefore, fragments of them really occurred in the drifts to the north, it would be an easy matter to trace them to their origin. It may be objected that the later glaciation may have ploughed out the older drift, and that, as the glaciers would necessarily follow the ordinary lines of drainage of the country, they would replace the Silurian drift by other drift brought from the Carboniferous uplands to the north. This will be referred to further on, when the drifts themselves are being treated of.

The scratches about Ingleborough have already been described in Mr. Tiddeman's paper *; they are reproduced on the accompanying map in order that their relations to the scratches that have been found in the country to the north may be easily seen.

Between Gragreth and Whernside two scratches ranging about N.N.E. have been found on the very summit of the pass; and one or two others having the same direction have been met with at lower elevations on the south side; but none of these affords any satisfactory evidence as to which side of that line of watershed the ice came from.

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* *Loc. cit.* p. 476.

Turning now to the southern end of the line marked A on the map, and which runs very nearly along the line of contact of the Silurian and Carboniferous rocks, we get evidence of a much more satisfactory character. To the east of this line we find that the drift is wholly made up of Carboniferous stones, while fragments of the adjacent Silurians are very rare, if not entirely absent; but on some parts of the west side of the line, Carboniferous drift extends some distance over the wonderfully *moutonnés* Silurians, while isolated boulders of Carboniferous origin range almost up to the summit at the north end of Barbon Fell. Further to the north the Middleton Fells afford evidence of the same kind, the Carboniferous drift from Dent having been thrust over part of the Silurian area, while to the east of the line A Silurian stones are not yet known to occur at all.

Any geologist who looks at the eastern corner of the Middleton Fells from Rysell, or from Helms Knot, cannot fail to notice the remarkable instances of glaciation on a large scale which these fells present. Professor Hughes long ago pointed this out in a paper read before the Leeds Philosophical Society. In lithological character these Silurians consist of alternations of hard and softer beds, tending under ordinary circumstances to weather into terraces that follow the lines of gentle curvature of the beds. When seen from a little distance, especially if the sun is not too high, the terraces are seen to be traversed by a great many roughly parallel ruts, which cross the strike of the beds at small angles. For short distances the glacial grooves coincide with the strike of the softer beds, and then mount the next bed above, and so on to the summit, beyond which the ice seems to have held its course nearly along the strike of the beds down to the Lune valley. Professor Hughes has pointed out that the ice-sheet must have split against the east corner of the Middleton Fells near Coum Scar, so that one branch of it flowed nearly along the course of Barbon Beck.

On the south side of Dent no satisfactory evidence can be got from the scratches; but on the eastern end of Rysell others occur on the top of the ridge with a direction about W. 30° S. It will be seen by the map that to the east of this several other striæ, having nearly the same direction, occur at various levels up to the 2000-foot contour, and that these high-level scratches seem to be in no way affected in their general direction by the form of the adjoining ground. In the cases just referred to there is no direct evidence to show which way the ice moved, although it is tolerably clear that the ice that overrode the Middleton Fells did not start from either Rysell or Widdale Fell, as the scratches do not radiate from the highest ground there, but point as if they went clean over it.

The writer has long suspected that part of the ice that filled the hollows where Widdale Beck, Snaizholme Beck, and Duerly Beck, at the head of Wensleydale, now flow, moved up those dales instead of down them, as would have been thought likely. In the two first-named dales the drift has not helped to make this point clear; but on searching on the high ground to the east of Dod Fell, at the head of

Duerly Beck, the writer found unmistakable drift, containing glaciated fragments of the Yoredale limestones, high up on the Millstone Grit of the watershed. Amongst the drift there were not only stones from the highest of the Yoredale limestones, easily recognizable by its encrinital character, but also fragments of some of the dark grey limestones that occur at much lower elevations. The value of this piece of evidence is great, as demonstrating that part of the ice that environed Ingleborough in so remarkable a manner came from still further north than the line of high ground between the Yore and Wharfe.

On Wetherfell, about two miles to the N.N.E. of the place where the up-carried drift was found on Dod Fell, Mr. Dakyns, of the Geological Survey, found scratches ranging south-easterly at an elevation of nearly 1800 feet above the sea. These afford another proof that the great ice-sheet flowed across the head of Wensleydale, and that its line of departure must therefore be still further to the north. The remaining scratches on the south side of the line of diamond-shaped dots on the map do not help to prove much; those in the low ground conform, as they usually do, to the direction of the part of the valley wherein they occur. The scratches on Sails, again, do not help much to show which way the ice moved; and the same may be said of those on the east side of Baugh Fell. There seems, however, to have been a line of ice-shedding nearly coincident with that between the head of Garsdale and the part of Wensleydale known as Lunds: to the north-east of this line the striæ trend to the south-east; and on the Garsdale side the lower striæ conform more or less to the direction taken by the river Clough. On the top of Baugh Fell several well-striated rock surfaces occur at different elevations between the 2100- and 2200-foot contours; their general direction is west-south-westerly, with a few pointing nearly due west. Scratched-stone drift occurs on the north side of the Fell up to 2100 feet above the sea. In this case the glaciation appears to have been very slight, as, in one or two instances, not represented by arrows upon the map, the ice seems to have done little else than plane off the crests of the ridges between the ripple-markings on the surface of some of the blocks, leaving the hollows in nearly their natural state. Other instances seem to show that the glacial action has only shorn off the upper parts of the quartz pebbles that weather out on some parts of the rock, leaving flattened surfaces that show very minute striæ preserving a generally parallel direction over large slabs of rock. These, however, may be partly due to the easy separation of the slabs of rock along the bedding-planes, in consequence of the small thickness of preglacially weathered rock that the brief stay of the ice at these high elevations enabled it to remove. The scratches represented upon the map are very well marked, and may be found easily enough by any one who cares to look for them.

Passing now to the drifts about Rawtha bridge, and those that occur just to the north of the Bluecaster diorite, we find unmistakable evidence of the northward transportal of the drift, and therefore that the line of ice-shedding must have been crossed. The drifts just mentioned contain stones from the Upper Old Red conglomerates, others from the Lower Limestone shale; and along with these well-glaciated fragments of the Bluecaster diorite come in the drifts to the N.N.E. Some of these drift-stones may be traced nearly three miles to the N.N.E. of the nearest rock of the kind in place.

On Swarth Fell east-north-easterly striæ occur at elevations between 1950 and 2200 feet above the sea, on the same bed of rock as that which has preserved the Baugh-Fell scratches. In one instance they are crossed by a set ranging nearly S.E. Some of the scratches are distinct enough; but the remainder are very slight, like those mentioned as occurring on Baugh Fell. None of these striæ prove which way the ice flowed.

On the watershed between Mallerstang and Lunds north-north-easterly scratches have been lately bared in the cuttings along the Settle and Carlisle Railway; and at Riggs, about a mile to the N.N.E. from the spot where these striæ occur, some remarkable veins of silicified limestone have furnished boulders which have travelled in a northerly direction. A reference to the map will show that it is probable that the line of ice-shedding here nearly or quite coincided with the present line of watershed between the Eden and the Yore.

A few other valley-striæ occur in Mallerstang, but they do not call for any particular remark; but on the bold line of Millstone-grit crags, known as Mallerstang Edge, a bed of gannister, on the same geological horizon as that which bears the glacial markings on Baugh Fell and Swarth Fell, shows two sets of striæ ranging north-north-easterly, at elevations about 2100 to 2150 feet above the sea. In these cases, again, there is clear evidence that the glaciation was but slight as compared with that at lower levels; for around the well-glaciated parts other striæ may be found, even on the same slab, which appear to be confined to the upper parts of the quartz-pebbles that project from the surface of much of the rock. Even on these the direction of the striæ is clearly parallel to that of the more obvious groovings near.

Crossing into Swaledale we do not find much satisfactory evidence anywhere south of the Swale to prove which way the ice went. In Sleddale Beck (one of the northward-flowing tributaries of the Swale) boulders of limestone from a faulted inlier have clearly been carried northward; as, however, this limestone lies not far above the bottom of a deep valley radiating from the highest ground within ten or twelve miles, later glaciers might be supposed to have acted as the means of transport.

At Keldside, after a storm, striæ were laid bare from under drift almost in the bed of the river Swale; and these clearly pointed right across the valley in which the river flows.

To the north of this in West Stonesdale there is abundant evidence to prove that parts of the ice moved across the valley of the Swale and up the tributary valleys to the north. Many boulders of grey limestone, of a kind that does not occur in this area above a certain horizon, have been carried far to the north of the nearest rock of the kind in place, and borne up hill to a point considerably above that reached by any of the parent rock in the neighbourhood. One of these boulders occurred at Lad Gill, near the Tan-Hill colliery, at an elevation of about 1600 feet above the sea.

Other striæ pointing in a generally north-north-easterly direction are found on Whitsundale Edge, and on the north side of Bakstone Beck; these are proved to have been caused by northward-flowing ice, by blocks of Millstone-grit having been carried across the Beck northward to rocks lower in the series. No other rock of the kind exists in place nearer than some which occurs in Teesdale, with the exception of that which is faulted in the valley of the Eden at the foot of Stainmoor: this grit, however, is much stained by Permian influences, so that blocks of it may be distinguished at a glance from any of the Swaledale Millstone-grit.

At Tan-Hill colliery, and on a hill a little to the north of it named Grey-grits on the Ordnance six-inch maps, several well-striated rock-surfaces occur, with the scratches ranging in a generally north-easterly direction. The central line of watershed of Northern England passes through part of this ground; and although there is no marked kind of rock in the drift to show which way the ice-sheet moved here, it amounts almost to a certainty that it came from the higher ground to the south-west—because in the opposite direction the surface gradually slopes for miles to the north-east, and there is no high ground again in that direction nearer than part of the Durham end of the great ridge that extends eastward from Cross Fell.

To the east-south-east of the striæ-bearing ground just mentioned lies the head of the comparatively wide dale known as Arkendale. The upper part of this widens out and merges into the slightly undulating tract of moorland most of which goes by the name of Stainmoor. The hills on the north side of Arkendale Head bear sets of striæ which have a generally north-easterly direction; the form of the ground shows that the ice that produced these must have flowed right across the Dale and over the north side of it into the basin of the Tees. The striæ in the other parts of Swaledale included in the map do not call for any particular mention: most of them show clearly enough that, away from the influence of the great icy stream that flowed northward from the high ground about the head of the dale, the lower ice tended more or less to flow in the direction of the principal valleys.

The details of the glaciation of the Dale district have been dwelt upon at greater length here than their importance might at first sight seem to warrant, because it was desirable to prove where the ice sheet that swept across the hills and valleys of Eastern Lancashire had its line of departure. If this can be made clear, and it can be shown that another similar ice sheet started from the same line of high ground, flowed alike over wide dales and high fells, and finally crossed from the basin of the Swale into that of the Tees on Stainmoor, many of the difficulties that are met with in accounting for the distribution of the Eden-valley drifts will be removed.

As it is here taken for granted that the glaciation of the Dale district was accomplished by a sheet of land ice of great thickness, none of the arguments which have been used to establish that point has been brought forward again. Mr. Tiddeman has proved its existence clearly enough in much of the country to the south of Swaledale; as, therefore, the glaciation of the Dale district to the north of the ice-shedding line resembles in every respect that to the south, there can be no reasonable doubt that they are both the results of one and the same cause.

If we now turn to the northern part of the country immediately to the west of the line marked A, taking up the evidence where it was left at the north-east corner of the Howgill Fells, we find that the drift on the limestone escarpment at Ash Fell is largely made up of Silurian stones, most of which have probably come from the Howgill Fells. Among these occur a small proportion of Old Red stones that may have been derived from the strip on the south side of the Lune. In following this drift towards the north we find the Silurian and Old Red stones becoming less and less common; and to the south of Kirkby Stephen they seem to be quite lost in the great accumulation of drift from the limestone country to the south. Just at this point, however, we meet with the Brockram, of which not a fragment has been found in the drift to the south of its present area of outcrop. A little distance to the north of its southern margin it begins to occur in the drift, glaciated like the stones that it is associated with, and from that line northward it is characteristic of the Eden-valley drifts over a large area.

It has been before pointed out that none of this rock in place lies above the 700-foot contour-line; but in following it in the drifts, in proportion as we advance towards the north-east, so we find it getting higher and higher, until, in the drifts that lie on the great line of watershed, it occurs at 1300 feet above the sea, or very nearly on the summit of the lowest pass of Stainmoor. There are other instances (to which reference will presently be made), in which the Brockram occurs at much higher levels.

Setting aside for the present any consideration of the evidence collected in Swaledale, it will be well to consider one of the only two theories of any value that have been advanced to account for the transportal of the Eden-valley drifts over Stainmoor.

It has been mentioned that none of the Brockram in place lies above the 700-foot contour-line, while the lowest pass of Stainmoor that any of it has gone over is, in round numbers, 1350 feet above the sea; that is to say, it is 650 feet above the highest rock of the kind in place. If it was carried over imbedded in floating ice, we shall be obliged to suppose that all the Brockram that went over Stainmoor was first frozen into the ice while the sea-level stood between the present 400- and 700-foot contours, and then that it was detained everywhere just a little to the north of the southern margin of the rock in place, until the relative levels of land and sea changed another 650 feet, after which the ice-rafts floated over and began dropping their burdens as they passed eastwards towards the vale of York. Probably most geologists will consider such a combination of circumstances so very improbable that they will reject the ice-raft theory as entirely untenable.

It is perhaps unnecessary to bring forward any other arguments to prove that the Brockram cannot have been transported by floating ice in any form.

It has been suggested that the difficulty might be lessened if it could be proved that there had been a considerable upheaval on the escarpment sides of the great faults in Postglacial times—in other words, if it could be proved that in Glacial times there was not so great a difference between the relative levels of the Stainmoor passes and the Eden valley as there now is. That no such Postglacial upheaval can have taken place is clearly enough proved by the fact that wherever the drifts that contain Brockram have lately been removed from the rock, this is always found to be striated, if the rock is of such a kind as to receive and retain scratches; and these glaciated surfaces are found at nearly equal elevations on both sides of the faults, often within a few hundred yards of the lines of disturbance. In addition to this the long mounds of Brockram-bearing drift extend uninterruptedly across the faults in such a way as to show that there cannot have been much, if there has been any, movement on one side or the other of the faults since the drift-mounds were deposited. Lastly, there is nowhere a rock-terrace, even of a few feet, on the escarpment sides of the faults; on the contrary, wherever the rock-surface is seen, it forms a continuation of the features on the other side of the line of disturbance. Denudation in Postglacial times will not account for this, because the drift-mounds before mentioned have been left in what must be very nearly the shape and size they had after the last trace of the ice sheet disappeared.

If it be conceded that the Brockram cannot have been transported by any form of floating ice over the Stainmoor passes, we are bound to accept the only other theory that will meet the requirements of the case, and conclude with Mr. Croll that here also a great sheet of land-ice has been at work.

The numerous striæ that have been found on the part of Stainmoor over which the Eden-valley drifts can be shown to have passed, indicate clearly enough in which direction the ice was flowing; a glance at the Map will show that they range nearly at right angles to the present lines of equal elevation; in other words, they point the shortest way to the summit. What yet remains to be accounted for before the land-ice theory can be adopted, is the agency that caused the Eden-valley ice sheet to move, as it has clearly done, from west to east—up hill, instead of along the ordinary lines of drainage of the country. Fortunately we have not far to seek for the required evidence.

Hitherto no mention has been made of any of the rocks that are associated with the Brockram in the Stainmoor drifts. If any thing definite can be made out respecting the means of transportal of any one of the kinds of rock in the drift, it is clear that all the stones that occur in the same way in the same beds of drift must necessarily have been carried thither in the same way.

In the northern part of the area included between lines marked A and B on the map (Plate II.), well-glaciated stones from the "Green Slate-and-Porphyry" series occur here and there in the Brockram-bearing drift. Most of this rock is quite unlike any of the Upper Silurians of the Lake district; these stones must therefore have come from the west.

Advancing a little to the north, we cross the southern line of dispersal of Shap granite. This line is marked B on the map, and does not differ materially from that drawn by Prof. Harkness in his paper on the distribution of Shap-granite Boulders*. It has been generally supposed that Shap-granite blocks are to be found only on the surface, and do not anywhere occur in true Glacial drift. But Prof. Hughes long ago found many unmistakable examples in the drift of different parts of Westmoreland, and the writer has since detected others; in fact, as has been pointed out by Mr. Gunn, of the Geological Survey, the number of Shap-granite boulders exposed in the drift bears as great a proportion to the superficial area of the sections of drift that are exposed, as the surface-blocks, numerous though they are, do to the whole area of the country wherein they occur. Well-glaciated boulders occur in abundance immediately to the east of Wastdale Crag itself; and although none of these are clearly seen in the drift itself, because no good sections are yet laid open, yet the fresh and unweathered appearance of those that occur at the surface speaks plainly enough of the lateness of their removal from the drift in which they were imbedded.

There is no need here to particularize all the localities in the Eden valley where Shap-granite boulders occur in drifts of the stiff-clay-matrix and glaciated-stone type. It is sufficient to state that it does occur as glaciated blocks in drift of this character, and that it is often associated with glaciated fragments of Brockram.

Passing now to the north of the line marked C on the map, in the country around Brough, the drift yields Brockram, Shap granite, and well-glaciated stones of all the Lake-country rocks that were mentioned as being made use of as tests of the direction taken by the drift. These stones occur in the drifts all the way from the summit of Stainmoor to the parent masses.

Perhaps the most remarkable boulders are those (nearly always small ones) of the syenite of Ennerdale, of the particular variety which Mr. Ward has shown to occur as boulders all the way from Buttermere to Cockermouth. Mr. Ward does not think that any of this rock has come down the dales to the east of that in which the river Cocker flows; so that its occurrence in the till on Stainmoor affords a very valuable piece of evidence, the importance of which will be shown further on.

Between the lines marked C and D respectively, the drift containing the stones above mentioned has in addition a number of glaciated boulders of rocks from Kirkcudbrightshire and Dumfries-

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* Quart. Journ. Geol. Soc. vol. xxvi. p. 517 (1870).

shire. Through the courtesy of the Messrs. Newall of Dalbeattie, the writer has been enabled to identify some of these with the grey granite which is now being so extensively quarried in the neighbourhood of Criffel for ornamental purposes; and Prof. Geikie of Edinburgh has spared the time to look over and name a box of stones which could not be traced to any rock in the Lake district, thereby enabling the writer to identify many of the far-derived stones in the drift, and affording a tolerably sure clue to the course taken by the ice. The result is that the writer has been enabled to prove the existence of great quantities of the drift from the south side of the Scottish southern uplands in the Eden valley, up to the top of Stainmoor itself. The stones are smaller and are less common as we advance towards the head of the valley; but there they are, glaciated, and associated in such a way with the boulders from sources nearer at hand as to leave no doubt that these Scotch boulders too were carried up to the summit of Stainmoor by the same stream of land-ice that bore the Ennerdale syenite up the Eden valley and over Stainmoor, instead of following the course it would take under ordinary glacial conditions, and moving westwards towards the low ground of the Solway.

Line D, coinciding in great part with the foot of the Cross-Fell escarpment, approximately represents the northern boundary of the Shap-granite drift; and beyond the area in which this rock occurs, the line represents, as nearly as can be made out at present, the north-eastern limit of the Scotch drift in the Eden valley above Brampton*. A glance at the course taken by the stream of Scotch drift ice will show at once that it had precisely the direction that, on its meeting with the stream from the western side of the Dale district and the Howgill Fells, would cause the combined currents to take the direction which the striæ on the slopes of Stainmoor, and the direction of boulder-dispersal, show that the ice had there.

In considering the causes that impelled the Scotch drift up the Eden valley, we have to bear in mind that to the east of Carlisle great quantities of the same drift have gone over the watershed between the Eden and the South Tyne eastward to the North Sea, and that therefore the transporting current seems to have moved in a generally easterly direction over the low ground about Carlisle until it reached the north-west corner of the Cross-Fell escarpment, against which it split, the southern half coasting along the escarpment itself, while the other passed into the valley of the South Tyne. The general direction taken by the ice sheet at the north-west corner of the Lake district seems to have been about N. 15° W. or N. 20° W. Eastward from this part the direction becomes more northerly; and finally, if we may judge from the form of the ground about Hawes Water, the course taken by the ice there must have been about N. 25° E., a direction which the map shows was maintained from near that part up to the edge of the Dale district.

If we can trust the evidence derived from the direction of trans-

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* Since this paper was written I have found far-travelled boulders some distance to the north of this line, near Melmerby.

portal of the Scotch boulders, the ice from Kirkcudbright and Dumfries must have flowed across the Solway in a nearly south-easterly direction, as thousands of boulders from the Galloway granite are scattered over the north-west of Cumberland. Such a stream of ice flowing in a south-easterly direction from Kirkcudbright, meeting with the opposing current from the north-west of the Lake district, must have resulted in the sending off of a combined current having a direction nearly magnetic east. About Carlisle the northern part of this stream must have had its direction again modified by the outflow from the local ice of the high ground between Eskdale and Teviotdale, which would cause it to take a turn still nearer to the east, while the southern part of the stream would be forced against the Cross-Fell escarpment and compelled to flow in a direction nearly parallel to it.

Once fairly in the Eden valley the slightest advance towards Stainmoor placed the upper part of the Scotch ice-stream more and more within the influence of the Lake-district ice, until, on meeting with the powerful north-easterly flow from the western side of the Dale district, the current was turned towards the comparatively low part of the escarpment near Brough and forced over on to the eastern side of the watershed.

It can hardly be doubted that the northerly line of fells ranging through High Street to the eastern side of the foot of Ullswater, backed up, as it is, by a still higher range extending from Helvellyn towards the high ground about the Caldbeck Fells, must have exercised a very considerable easterly impelling influence upon the upper parts of the Eden-valley ice. The fact that the striæ found on these fells show that the ice moved in the main along the valleys does not at all disprove the existence of higher currents flowing in other directions.

It has been remarked that one of the greatest difficulties we meet with in trying to account for the drifting of the boulders over Stainmoor is that many of the ice-markings seen in the Eden valley are plainly right across the path taken by the drift. Prof. Ramsay's theory that there were currents flowing in various directions at different levels in the ice-sheet over any given spot helps to explain not only this, but, as will be shown further on, much else connected with the drift that would be difficult to explain in any other way. As before observed, much of the ice that filled the Eden valley came from the high ground to the south; and the easterly drifting of the boulders has been inferred to have resulted from the meeting of the northerly-flowing local ice with the stream that flowed parallel to the escarpment. Therefore it is probable that at low levels the local ice would be pressing outwards far to the north of the currents which, in the higher parts of the great stream, were flowing eastwards full of boulders. In this way it is easy to explain the existence of the scratches at Gathorn near Crosby Ravensworth which are referred to by Prof. Harkness in his paper on the distribution of Shap-granite Boulders. These striæ lie at, or near, the bottom of a valley which lay exactly in the path of the ice coming from the Howgill Fells; so that it is not improbable that an undercurrent of local ice flowed northwards along this hollow, while at higher elevations the main stream conformed to the general direction taken by the Eden-valley ice.

The influence of the local ice upon the Eden-valley stream generally is well shown near Tebay, where the map (Pl. II.) shows that the southern boundary of Shap-granite dispersal has been deflected a long way to the south, because just about there a considerable depression exists, and the local ice does not seem to have risen high enough to keep the Eden-valley stream so far from the Silurian country as it has done in the neighbourhood of higher ground. So too with the same boulders in the valley of the Bela. Here the north-easterly-flowing ice passed over a deep valley in which the lower layers of the ice were sheltered from the northerly impelling force that affected the upper part; and in consequence, the south-easterly-moving Eden-valley ice, meeting with less cross-resistance, flowed up the valley, striating the rocks and forcing the Eden-valley drifts up the ravine. This is still more evident with the Brockram drift in the same valley; the map shows that there is a deflection of the boundary-line of this drift two miles and a half out of the course it has taken to the south. It is as well to mention that this does not rest upon negative evidence, because the numerous drift-sections to the east of the line (A) do not yield a single stone that may not have come from the Carboniferous district to the south.

We have therefore in these cases clear proof that while the higher strata of the ice sheet were moving steadily forward in a north-easterly direction, the lower layers, being sheltered from much of the northerly impelling force that urged on the upper strata, and being at the same time acted upon by a like amount of south-easterly impelling force as affected the ice to the north and south of the Bela, were forced in a direction nearly at right angles to the course taken by the upper part of the ice sheet over the same ground.

Only some such explanation as that given by Prof. Ramsay will account for the fact that while the ice near the low ground in the Howgill Fells and the adjoining parts of the Dale district was shed nearly along the line indicated by the dots on the map, some of the higher strata moved in directions nearly at right angles to the course taken by the underlying streams. It is impossible to give any satisfactory explanation of the striæ on Swarth Fell and Baugh Fell if they were not caused by ice flowing from the high ground at the head of Mallerstang. It has been shown that in Mallerstang itself the drift moved towards the north—perhaps because the ice had no other course open to it; but at higher levels, where there were fewer obstructions, the ice would flow everywhere away from the highest ground. That the Baugh-Fell, and especially the Swarth-Fell striæ were produced by ice coming from the head of Mallerstang seems to be almost proved by Prof. Hughes finding Carboniferous sandstone in the drift on the north-western side of the highest ground of the Howgill Fells. Most of the adjoining Carboniferous Fell-tops are higher than any part of the Howgill Fells; it is therefore quite likely that some of the higher strata of the Dale-district ice, laden with Carboniferous fragments, flowed over the Howgill Fells towards the lower ground of the upper part of Lunedale.

Owing to this diversity of directions taken by the various strata of the ice over any one place, it is next to impossible to draw any line that shall indicate precisely where the line of shedding was: that represented upon the map (Pl. II.) must be understood to be an approximation to the shedding-line of only the lower part of the ice-sheet thereabouts.

The instances of cross-glaciation mentioned as occurring in the Eden-valley seem to show that the component forces that resulted in the easterly turning of the Eden-valley ice-stream must have been very nicely balanced; so that where a stronger current from the south set in, the Eden-valley ice was sent further to the north, and, on the other hand, where the local northward-flowing ice exerted less power, the Eden-valley stream advanced towards the line of ice-shedding. In this way we can easily account for the fact that none of the Eden-valley ice, after crossing Stainmoor, found its way down Arkendale into Swaledale. There is nothing whatever in the form of any of the surrounding ground to prevent a marine current from passing that way; on the contrary, every thing seems favourable for a dispersal in that direction; but, as a matter of fact, there is not a single fragment known of any rock in the drifts about Arkendale Head that may not have been derived from the rocks near at hand. One can understand this easily enough when it is known that a thick sheet of ice from the Fells at the head of Swaledale flowed right across the head of Arkendale, and kept the Stainmoor drifts a long way to the north of the line they would have taken had no such ice-sheet been in existence; but how are we to explain these facts by any theory of marine action?

No reference has yet been made in this paper to the dispersal in a southward direction of Shap granite in the basins of the Mint and Lune on the south side of the Lake-district watershed. This was almost certainly owing to the lowness of the ground between the Shap-granite area and the Howgill Fells, in consequence of which the local ice had not sufficient bulk to keep the upper part of the Eden-valley ice-stream far enough to the north to prevent its overflowing into the area south of the watershed. The striated rock-surfaces indicated on the granitic area itself seem to bear out this conclusion, as the rounded sides of the rock face to the north, as if the ice came from that direction. There seems, however, to be some reason for thinking that this cannot always be relied upon as a test of the way the ice flowed, as in one instance, in Garsdale, where it seems tolerably certain which way the bulk of the ice went, the rounded surfaces face away from the source of the drift. This may be due to a local variation in the ice-current; but at any rate it will serve to caution us not to trust entirely to the appearance of the dressed surface as evidence of the direction of flow of the ice.

It seems that there are but few glaciated districts that afford an opportunity of making an approximation to the thickness of the ice that covered them at the climax of the Glacial Period. But one may venture to assume that the very slightly glaciated rock-surfaces above the 2200 contour-line on the western side of the Dale district prove that the ice cannot have had a much greater thickness than the height of the highest ridge of land over which it can be proved the ice-sheet flowed. Apart from the evidence of the limited amount of glaciation on hard rock-surfaces, we seem to get other evidence in favour of this supposition in the fact that the soft shales and thin interbedded flagstones that occur on the highest ground of the Dale district nowhere exhibit any of that remarkable surface-crushing and contortion so often met with on the surface of beds of the same character at lower levels. After considering all the evidence, there does not seem much probability that the surface of the ice of the Dale district ever rose much above the 2300 or 2400 contour, if it ever was so high as that. If we assume that the ice reached an elevation of 2400 feet above the sea about the line of departure, the fact that it flowed away to the north would seem to prove that the Eden-valley stream must have had a lower surface. Had it been higher, some of the ice from the Dale-district Fells would have been ponded back, and must have flowed southwards from the Eden valley. It is clear that the lower strata of the ice did not do so; but there is only the negative evidence that no Eden-valley drift-boulders have gone south of line B anywhere, and that the ground rises more than 1500 feet above the sea, to prove that the upper part of the ice did not flow southwards from the Eden valley.

From what has been stated about the causes that impelled the Eden-valley ice over Stainmoor, it will be seen that the thickness of the ice that came from the southern uplands of Scotland need not have been greater than the local ice of the Lake district. Mr. Ward finds no striæ above the 2500 contour-line. As this ice flowed steadily away northwards, it would seem to prove that in the north-western part of the Eden valley the Scotch ice cannot well have exceeded 2400 or 2500 feet in thickness—a conclusion which harmonizes well with that derived from the investigation of the Dale-district glacial phenomena.

Glacial erosion.

Such a sheet of ice as that with which the area treated of in this paper was enwrapped must have exercised a very powerful denuding force upon the low-lying parts of the country; but there seems as yet no satisfactory means of determining what thickness of rock was removed from any given spot. One thing, however, is tolerably clear: although the great ice-sheet did undoubtedly deepen many valleys where these happened to lie in its course, there are other cases in which it can be shown that the ice has tended to make them relatively shallower by grinding down the intervening ridges, in districts where the lower parts of the ice were forced across the lines of drainage.

In one part of the Eden valley, near Crosby Garret, we have satisfactory proof that the deep hollow in which Scandal Beck now flows was not initiated by glacial action, although its direction so nearly coincides with that of the flow of the ice there; for we find patches of Permian rocks in the very bottom of the valley, proving beyond all doubt that a ravine existed there in pre-Permian times.

It may well be doubted whether many instances of considerable valleys which have clearly originated by glacial action can be pointed out, as it is nearly always difficult, if not impossible, to prove that they are wholly the work of ice. The evidence seems rather to prove that the ice ground down most of the minor inequalities of the surface, and thereby tended to efface the preglacial channels of the lesser streams, and that, where the pressure and rate of flow of the ice were nearly uniform over large areas, it tended to level these into plains instead of ploughing out great parallel furrows in them.

In those parts of the Dale-district valleys where the lower strata of the ice can be shown to have flowed nearly along the windings of the dale, the alternations of hard and soft beds that make up the dale-rocks have given rise to more striking terraces than are to be found in other parts where the ice is known to have crossed the lines of outcrop at a greater or lesser angle. Where the direction taken by the ice has nearly or quite formed a right angle with the line of outcrop, we generally find that the characteristic surface-features of the dale-rocks are entirely wanting; and even where there are thick beds of limestone, the long lines of swallow-holes that almost everywhere else accompany beds of limestone in the dales, are generally absent. In the terraced parts of the dales, no matter what may be the width of the terrace, the swallow-holes, save an occasional one here and there, are only to be found along the line where the usually soft overlying beds come on. In no instance yet known to the writer do these swallow-holes extend far from the inner margin of the terrace towards the scar at its outer edge. In addition to this it is unusual to find the limestone of the lower terraces much more weathered, or wider joint-fissures developed in it nearer the scar-margin, than may be found all over its surface up to the swallow-holes.

In considering the causes that may have helped to shape these terraces, we may leave marine action entirely out of the question, because they are confined to particular beds of rock, and go with them through all their variations of dip and elevation. Streams rarely run along the foot of the scar or along the inner margin of the terrace; and those that do so are so small that they cannot remove any appreciable quantity of weathered débris from the rock above. Springs can do little else than undermine the part of the scar from which they issue, and in that way cut it back into a notch; the greater the number of springs issuing from the base of a scar, the more is it notched and changed in outline.

Landslips can effect but very little. It is true that great masses of rock are frequently removed from the scars in this way; but the crescent-shaped hollows that are left, and the great heaps of fallen material remaining at the foot of the scar, are very different from the sweeping curves and generally unencumbered lower slopes that are usually seen about the lower terraces. Some of the scars are more than 1000 feet above the bottom of the adjoining valley; and as no stream could possibly flow along the slopes in such a way as to carry off the talus from the scar, unless the valley were shallower by several hundred feet than it is at present, river-action cannot be taken into account, unless it can be shown that in the north of England, with a high rainfall, a river can cut its channel down more than 1000 feet while the scars above only recede a few feet from the line at which they were first formed. Many of these scars, too, can be shown to follow the undulations of the beds, so that the top of the scar at one place is often much lower than the base at another a few hundred yards off.

Ordinary weathering in nearly every case is tending to cut back some of the most precipitous scars into rounded slopes. Where the scar is of limestone it is often banked up by a talus of small weathered chips detached along the joints and bedding-planes from the higher part of the scar; and it is obvious that, unless a stream is at work below carrying off the weathered material, the talus will accumulate, protecting the lower part, while the top of the scar weathers back into a low slope, the result being a small escarpment quite unlike the bold lines of scar seen in the dales.

Professor Hughes pointed out to the writer in 1868 that the subaerial agents just referred to were inadequate to produce much of the present form of the ground in the dales, and that land ice must have had a large share in bringing the rocks into their present shape.

When we know that in the upper parts of Wensleydale and Swaledale, and in some of the adjoining valleys, the ice must have been at the least 1600 feet in thickness, the facts mentioned above become intelligible. It is easy enough to understand how such a mass of ice—charged throughout with stones of all sizes, and flowing between fells which are made up of alternations of hard and soft beds lying nearly horizontally—would cut with most ease into the soft beds, so as to leave much of the less easily eroded rocks standing out as terraces and scars. This explains how it is that the swallow-holes are confined to the inner margin of each terrace, and that the terrace is nearly uniformly weathered all over. All the preglacial terrace, swallow-holes, joints and all, was carried away by the ice; and when this disappeared a new surface of rock was left for the weather and streams to act upon.

The next hill-slope above the terrace has been cut back so little in Postglacial times that it is often not more than a few feet from the centre of the swallow-hole—that is to say, from the position in which it was left at the close of the Glacial period.

Glacial markings are occasionally met with on these terraces close up to the inner margin, affording another proof that they are nearly as the great ice-sheet left them.

This theory helps us to understand how it is that on some of the hill-slopes terrace above terrace exhibit so remarkable a conformity of curvature, thus plainly enough pointing to the oneness of their origin. We can also see why it is that these curved lines of scar are so frequently opposite to the mouth of some large branch dale, the ice from which compelled the main stream to curve against the opposite bank.

If now we turn to those parts of the dales where the ice has flowed up the cross valleys and across the lines of outcrop of the beds, instead of the terraces and scars observable in other parts of the dales, we find the hill-sides ground into smooth slopes, with nothing at the surface to mark the diversity in lithological character of the rocks beneath. In the case of the dales on the south side of Wensleydale above Hawse, wherein Snaizholme Beck, Widdale Beck, and Duerly Beck flow, we have some instances of regularly curved hollows just at those points where the form and direction of each dale would cause the ice from the high ground to the north to take a slight curvilinear motion, which resulted in the grinding-down of preexisting irregularities into sweeping curves. Looking at the beautiful "coum" at the head of Snaizholme Beck, one cannot help being convinced that nothing but ice could produce such a result. Springs, as before pointed out, tend rather to cut the rock back into notches; and, moreover, in the dale rocks they act only along certain definite lines. Streams act still more powerfully in forming ravines, quite unlike any of the smooth concave hollows here referred to. And, lastly, the ordinary action of the weather tends to encumber such slopes with the ruin of the higher rocks. But in the instances here referred to comparatively little weathered material lies on the hill-sides; and in the case of the Snaizholme coum the slopes are nearly bare, except where a thin covering of drift clings to them and hides the rock.

Many other instances of similar coums could be adduced; but one other instance from the Dale district will suffice. It was pointed out above that the ice-sheet crossed Dentdale in a south-westerly direction in flowing towards Lunedale. Part of this stream, as the ice-markings show, passed in a south-south-westerly direction up Dibdale. At the head of the dale the stream divided against the Nab, one branch going off to the south-west and turning against Gragreth, the other taking a south-south-easterly course and curving against Whernside. The result is that we have two coums which, if not so striking as the Snaizholme coum, show a greater height of curved surface. That on the west side of Whernside can be traced upwards for at least 1000 feet—the curves opening with great regularity, from one of a radius of about a quarter of a mile near the bottom, to the curved line of grit scar, at the top of which the radius is about a mile.

When we compare these coums with the other rock-features of the district, there is seen to be a perfect gradation from a nearly straight line of scar, through others more and more curved, to such a coum as that at the head of Snaizholme Beck.

In many other places where the form of the ground has caused the ice-stream to turn in its course we find more or less perfect examples of these concave rock-surfaces; so that it is difficult to avoid the conclusion that out of the Dale district the same causes have been at work, producing these cup-shaped hollows among the fells wherever local circumstances compelled part of the ice-sheet to move in a curve.

In the numerous instances in every mountainous district where the upper parts of the ice would be influenced more by the form and direction of the adjoining high land than by the general trend of the valleys, there is a strong probability that wheeling movements were communicated to parts of the ice. The axis of rotation would of course vary in direction according to local circumstances: in some cases the ice may have moved downwards in a curve as a kind of undertow to the glacial stream that was crossing a col into another valley; but in the majority of cases the tangential motion may have resulted from the meeting of cross currents in, or nearly in, the same plane. There can be little room for doubt that any such eddying of the ice, charged throughout with stones, must have operated very powerfully in smoothing preexisting hollows into more regularly concave coums; and it is perhaps hardly out of the question that in soft or easily eroded rocks the long-continued action of the ice may have excavated many such hollows where nothing of the kind existed in preglacial times.

Origin of Drift-deposits.

Before discussing the origin of the Eden-valley drifts in any detail, it will be well to make a few general remarks upon the various deposits which by one cause or another were left at the close of the Glacial Period over the greater part of the area treated of in this paper.

In the Dale district the order of the drifts is as follows, beginning with the lowest:—

No. 1. Stiff clay, full of well-glaciated stones, apparently devoid of stratification; usually lying in the bottoms of the higher parts of the main valleys, and generally found along the whole length of the bottom of the branch dales, except where these are far from the head of the principal valley.

No. 2. More angular drift, containing fewer scratched stones and having a more sandy matrix than No. 1. In the higher parts of the valleys it becomes still more angular and loosely aggregated in proportion as it nears the highest ground. It frequently extends up to or above the 1800 contour in the form of an irregularly sloping plain; but thin patches of drift of the same character may be found nearly up to the tops of the fells, where it seems to pass into a kind of surface-wash in which an occasional scratched stone may be found. This is not merely a weathered part of No. 1, but maintains its characteristics to a great depth from the surface, at which no larger proportion of glaciated stones can be found than are to be seen near the outside of the deposit.

No. 3. Still more angular drift, quite devoid of stratification, very loosely aggregated, and free from clay; scratched stones very rare; big angular blocks occur in abundance. It generally forms very moundy ground high up above the valleys, and has not been detected within a radius of several miles from the highest part of the Dale district. It has altogether a very morainic look; and although in the mass it may be separated from No. 2, smaller deposits of it are distinguished with difficulty; and such sections as exist seem to show that there is a gradual passage downwards into No. 2.

These three divisions are seldom sharply defined; and although one or two sections seem to show that No. 2 lies on an irregular surface of No. 1, it is impossible to draw a sharp line between any of them over large areas. In the bottoms of the valleys, at variable distances from the nearest line of high ground, we find thin seams of finely stratified sand alternating with sheets of tough finely laminated clays with and without included stones, and associated with occasional beds of gravel, of which a few of the stones bear half-obliterated glacial striæ. These are overlain by more or less clayey beds of No. 2, that frequently show obscure stratification near the base, and are clearly seen to occur above the till, No. 1. The sand and gravel passes down into No. 1 and up into No. 2 in such a way as to point to the oneness of origin of the whole.

Further from the head of the dale sections in the low-lying drift mounds show that, on the whole, the proportion of washed materials increases towards the low end of the valley, thicker beds of sand come in, the glaciated stones become more and more waterworn, and the overlying beds referred to No. 2 become cleaner and show more decided traces of bedding. Still lower down the valley mounds of sand and gravel, with included seams of clay and hardly any glaciated stones, come in: the mounds themselves are often several hundred yards apart, and sections occur only at irregular and often distant intervals; but the similarity of the contents to those of the thinner deposits seen higher up the valley, and the close resemblance in the form and disposition of the higher and lower mounds, would seem to lead to the inference that they are in some way the work of the same agency, although it is impossible to prove it.

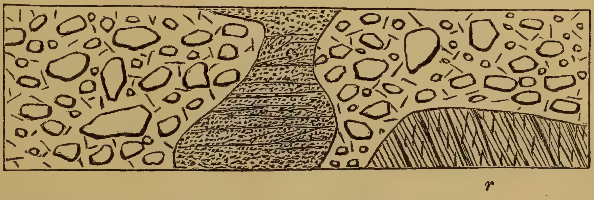
Many of the thin sheets of laminated clay referred to above seem as if they had been originally thrown down at considerable angles, as the seams of sand above and below do not always show any sign of contortion. In so many instances have these sheets of laminated clays been met with inclined at various angles, that it seems quite the exception to meet with any that are horizontal, unless the section is at a great distance from the head of the valley. In many cases, hereafter to be referred to, it is quite clear that the inclination of these beds of laminated clay is that of original deposition. This point being well established, it follows that the drifts in which these clays occur cannot have been deposited under water, and must therefore have their origin accounted for in some other way.

Hitherto all the cases of inclined or contorted strata in the drifts seem to have been regarded as clear proofs of the grounding of floating ice; hence it would follow that wherever contorted beds occur, there the sea must have been in glacial times. It will be shown further on that this kind of evidence is, in many cases, at least equivocal, and that several other causes must have been at work producing the appearances in question. Some of the laminated clays contain angular and glaciated stones; and in a few instances, where the lamination is not very evident, it is not easy to distinguish them from ordinary till.

In the dales the mounds of sand and gravel are found at intervals from near the highest place where sand begins to appear in the drift downwards towards the mouth of the dale; but they seem to attain their greatest development about the mouths of the larger tributary valleys. In proceeding towards the lower parts of the dales the gravel on the whole does not appear to become much more waterworn. This is probably due to the share the larger tributaries have had in contributing towards the contents of the gravel-mounds, so that it is not an unusual circumstance to find mounds of slightly washed gravel a long way below another part of the dale where the striæ are nearly obliterated from most of the stones.

In one of the Settle and Carlisle Railway-cuttings near Horton-in-Ribblesdale the line has passed through a deposit of tough clay, full of glaciated boulders, and quite of the character of ordinary till. In one part a flask-shaped deposit of finely laminated and false-bedded sand and thin seams of clean gravel occurs surrounded, certainly on three sides, by the above-mentioned clay-drift (fig. 1). There is not the slightest sign of any contortion; and the deposit is clearly not due to river-action, because the sides of the nest close in rapidly above, and the railway-cutting shows plainly enough that the sand does not extend even as far as the western bank.

Fig. 1.—*Section in the Settle and Carlisle Railway-cuttings near Horton-in-Ribblesdale.*



Undisturbed nest of finely stratified sand and gravel in till. *r*. Rock. Length 30 ft.

If this stiff clay full of glaciated stones is part of a *moraine profonde*, how is this undisturbed nest of sand, which extends upwards for at least 10 feet, to be accounted for? The ice that this drift is supposed to have accumulated under cannot have been less than several hundred, perhaps it was more than a thousand feet in thickness over that particular spot; it is therefore obvious that the forward movement of such a mass a single inch must have resulted in the kneading up of all the sand into the drift in such a way that every trace of stratification would be obliterated.

All the drifts mentioned above contain a far smaller proportion of clay than we should be led to expect, when we take into account how much shale there is in the dale-rocks. Taking them altogether, it would perhaps be rather an underestimate if the proportion of shale to the whole mass of rock in the area here treated of were set down at one half. Yet extensive deposits of drift may be met with, into the composition of which clay hardly enters at all. Even in the till, the most clayey of all, it is doubtful whether the proportion of clay to stones is any thing like that of the shale to the other beds.

Again, if we consider how large a proportion of limestone and of some of the finer and softer sandstones must have been ground into mud by the ice, it is not very easy to understand how any very large proportion of the drift can really be the *moraine profonde* of a great ice-sheet. An enormous quantity of clay must have gone out of the dales somewhere; and it certainly is not clear how the ice should carry away so much of the finer detritus of the rocks that it passed over, while it left the coarser parts behind. A possible explanation of this may be that the greater part of the stones in the drift may be but the remodelled result of the preglacial weathering of the dale-rocks—that, in fact, the drift is but a mass of glaciated stones originally derived from the old fell-side screes. The objection to this is, that wherever any bed of rock occurs of such a lithological character that it can be traced with some degree of certainty in the drift, it can almost always be proved that it has travelled many miles, in some cases even hundreds of miles, from the parent source—as, for example, the Shap granite, which has gone as far south as the Vale of Gloucester. What, therefore, is true of any marked bed of rock, must be equally true of all other rocks that have undergone the like amount of glaciation. It is therefore very unlikely that any large quantity of the old subaerial waste of the dale-rocks has been left anywhere near where it was when the ice first reached it. Judging by the distances other rocks can be proved to have been transported by the ice, the thick accumulation of preglacial surface-waste must have been swept away to great distances. Hence, instead of looking for traces of such detritus near the parent rocks on the eastern side of the watershed, we should rather expect to find them somewhere about the east coast, or in the North Sea, if there were many stones tough enough to withstand the effects of a transportal to so great a distance.

When we turn to the drifts of the upper part of the Eden valley, we find nearly the same order as obtains in the dales. The lowest drift of all is of the character of the ordinary till, a stiff clay of various colours, according to the kind of rock that most of it was derived from, and full of stones, most of which are well glaciated, and are generally of comparatively small size.

It is not always possible to distinguish the till from the deposit that overlies it. Occasionally, and especially in the vicinity of low ground, the upper division is quite as clayey in the matrix, and contains as large a proportion of glaciated stones as the ordinary till. On the other hand, in the smaller valleys the clayey till seems to thin away, and to be represented by drift resembling that found under similar circumstances in the Dale district.

Wherever we have an opportunity of determining to which division any particular patch of drift belongs, we find that the higher drift contains the bigger and more angular blocks, and that there seems to be a larger proportion of far-derived boulders in it than has yet been detected in the lower division. But on this point one cannot always be quite sure, as, unless the section is very deep and kept quite clear, it is but rarely that the underlying beds can be examined. In the few instances in the Eden valley where a deposit answering to the true till is laid bare, it *has* yielded stones which have undoubtedly come from a distance. The other stones in it, although they have not travelled so far, have yet been transported long distances in precisely the same direction as those in the overlying drift.

The drift sections in Swindale, above Brough, afford good instances of this. At Swindale Head, at an elevation of about 1350 feet above the sea, a thin bed answering to the description of the till occurs under a much thicker mass of more loosely aggregated drift. A few of the ordinary Eden-valley drift stones occur in the upper deposit, most of them having a more local origin than those that are not so near the boundary line of the up-travelled drifts. In the tough tills beneath, we have a stiff clayey matrix of a deep red colour, which is derived from the wear and tear of the Permian rocks of the Eden valley. Among the stones several recognizable fragments of Brockram may be detected, thus proving that this till, like the very different upper drift, has moved upwards from the Eden valley, and that both drifts have moved in the same direction. It should be noted that this red till is nearly 700 feet higher than any of the red rocks from which it must have been derived.

The only exposures of the lowest drift on Stainmoor are in different parts of Swindale Beck. The numerous sections in the higher drift that is considered to be the equivalent of No. 2 of the Dale-district drifts, show that it has a tolerably uniform character nearly everywhere on the high ground. The stones in it vary as regards origin, according to the position of the mound where they occur. The mounds to the east of line A (Pl. II.) contain nothing but what might have been derived from local rocks. Between A and B the stones have come from a greater distance. Lines B and C enclose mounds which contain Shap granite and many rocks from the Lake country, in addition to others that have not travelled as far. And, lastly, the area included between C and D is that in which the drift includes detritus from the north of the Lake district, the various kinds of granite and other igneous rocks from Galloway, and a few perhaps even from the Lower Old Red Sandstone at the head of Nithsdale. Yet the general parallelism of the drift mounds, and their similarity in form and size from the lowest ground up to the highest point where they occur, whether their contents have come from a great distance or are confined to detritus derived from rocks within the physical basin of the Eden, leave little room for doubt that they were all thrown down in the same way.

In the low ground at the foot of Stainmoor a few sections show that locally a threefold division of the drift obtains. The section at the scar alongside Swindale Beck under Brough Castle may be taken as typical, as no other so good is to be seen anywhere else in the neighbourhood. At the bottom of the scar the beck has cleared a deposit of tough red clay, with seams of red laminated clay, and including blunted and glaciated stones, of which a few are quite angular, and some big enough to be called boulders. About 20 per cent. of the stones are known to be from a distance, as unmistakable fragments from the "green-slate-and-porphyry series" and other Silurian detritus occur; the rest seem to be of Carboniferous and Permian origin. As these, however, have no distinctive character whereby they might be referred with certainty to the rock of any particular place, some of them may have come from the north-west end of the Eden valley for aught that could be said to the contrary. No Shap granite nor any traces of Scotch drift could be detected, perhaps because the very limited area exposed gives one but little opportunity of making a fair estimate of the true percentage of far-derived stones.

The upper part of the till exhibits more distinct lamination, which is well shown by the presence of thin lines of sand and fine gravel, and, in the absence of these, by the unequal weathering of the alternate clayey and loamy bands in it leaving the tougher clayey laminæ in slight relief. Where the beck washes beds of this kind it acts in much the same way, only that inclined and convex terraces several inches in width are developed in the laminated clays by the gentle washing of the stream. Obscure traces of plants occur on the bedding-planes of a few of these tough clays; but none could be got out perfect.

One cannot help being struck with the number of instances of inclined laminæ of this fine clay, with and without stones, which are found; but from the top to the bottom of the scar not a trace of any thing like contortion can be found in any of them.

The slopes above the part of the scar where the till is seen are obscured for about 10 feet by slips from the higher beds; but it is said that courses of sand occur in it. Above this point the writer employed some men to clear the section up to the Castle. They laid bare about 25 feet of finely bedded straw-coloured sand, with lenticular seams of coarse and fine gravel, layers of stony clays, and occasional thin sheets of tough gutta-percha clays without stones. Near the lower part of the clearing the beds just mentioned alternate with irregular patches of stiff clay drift with glaciated stones in no way different from the ordinary till of the neighbourhood, except that they are not quite so red as the till seen lower down by the beck-side. The stones from the interbedded patches of till and those in the gravel seams have about the same percentage of far-derived stones as occurs in the lowest bed. In the upper part of the section the same alternations of sand with beds of till were found; but in passing upwards the seams of gravel and sand become thinner, and the interbedded till gets thicker, until an almost undivided mass of clay-drift with glaciated stones and boulders up to 4 feet in diameter is met with. A large surface of this upper clay is exposed, and yields many subangular, blunted, rounded and glaciated boulders of Shap granite. Other rocks represented were two or three varieties of Galloway granite, blocks and fragments of the syenites of Carrock Fell, St. John's Vale, and Buttermere, as well as other Lake-country rocks in abundance, stained Carboniferous detritus from the Eden valley, and much Permian sandstone and Brockram.

The mound in which these drifts occur is one of a great series of chains of drumlins which trend in sweeping curves from the lowest parts of the Eden valley, in one case nearly up to the Stainmoor watershed. Their direction seems to have been influenced in nearly every case more by the contour of the nearest high ground than by the direction in which the bulk of the drift was transported. In those cases, however, where the ice was guided in its course by the form of the adjoining high ground, not a few of the longer axes of the drumlins lie nearly in the same line that the included boulders have travelled in.

Here and there in the country below Brough, a section shows that seams of sand and gravel are interstratified with beds resembling true till; but, owing to the disconnected nature of the drift deposits, and the fewness of good sections, it is impossible to prove the identity of even the larger groups of sand and gravel in adjoining mounds. On the whole, however, it is tolerably clear that in the low ground the proportion of washed detritus associated with the clay-drifts is greater, and the signs of lamination in the clay-drifts more marked and more widely spread, in proportion to the distance from the head of the main valley.

It is nearly impossible to make out any definite order of succession in the drifts in the lower parts of the valley; the few sections seen show plainly enough that masses of sand and gravel pass into, and are interwoven with, clay-drifts in such a way as to defy any attempt at separation over large areas, although single sections may be indicated which do show a definite sequence. The larger branch valleys from the Lake district have further added to the complication by contributing quantities of more or less well washed drift, which lies in mounds the axes of which are often at right angles to the length of the tributaries from which the drift materials were derived, in such a way as to show that they were heaped up by the same cause that gave the adjoining drumlins their present form and position.

Much of the Eden valley below the 500-foot contour between Musgrave and Lazonby lies in two old rock-basins, the lower lips of which are formed by the Permian rocks that close in upon the river at Eden Lacy, and again between Lazonby and Armathwaite.

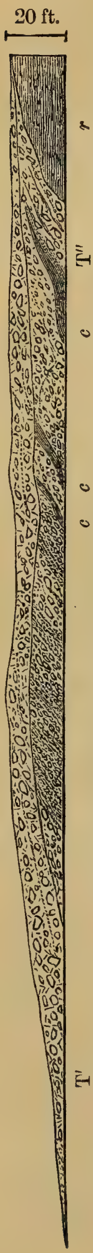


Fig. 2.—*Generalized Section along the Settle and Carlisle Railway at Culgaith.*

Alternations of beds of sand and gravel with laminated clays between two beds of till. T'. Upper till. T''. Lower till. c. Laminated clays. r. Rock. Length about 350 yards.

From evidence that will be referred to again it is almost certain that these great rock-basins could not have been filled with water to any depth while the drifts were being deposited, although the presence of alluvial terraces high above the present beds of the rivers of that part seems to point to the existence of a shallow lake of considerable extent in postglacial times, which may have been due to the presence of a barrier of drift mounds ponding back the natural drainage of the district. It is only referred to here because the rock barriers must have acted as bars to keep the sea out below the 450-foot contour, so that the absence of any thing at all resembling marine Boulder-clay above them is easily enough accounted for.

The cuttings now being made along the Settle and Carlisle Railway in the Eden valley afford some very instructive sections in the drifts. Above Culgaith there is not much that calls for any particular remark; but at the north-western end of the tunnels between that village and Longwathby the railway crosses the axis of a drumlin at a small angle, so that a very instructive section is laid bare. At the south-eastern end till, with the ordinary far-travelled boulders of the Eden-valley drifts, and obscurely stratified, is seen overlying beds of "marl" belonging to the middle division of the red rocks of the Eden valley. Overlapping the till is a series of alternations of diagonally bedded sands and gravels with finely laminated clays. Another mass of till, which is quite undistinguishable from that seen at the base of the series, covers all the beds from the northern end of the cutting to the solid rock. Fig. 2 will perhaps serve to make this clearer*.

The most remarkable point about the whole series of deposits is the singular uniformity of inclination of all the beds below the upper till that show traces of stratification. Some of the beds of laminated clay are seen lying at angles of from 25° to 30°, and in some instances at even higher angles than that, proving, beyond the possibility of a doubt, that they could not have been deposited under

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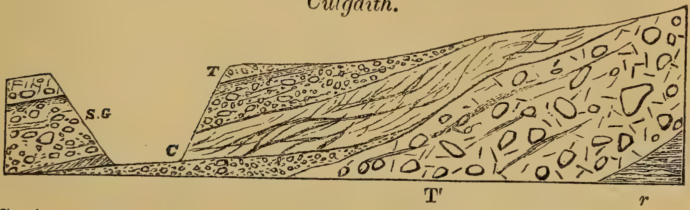
* In the woodcut the gravels at the left hand of the section are represented as too highly inclined. The true inclination is nearly that of the base line of the overlying till.

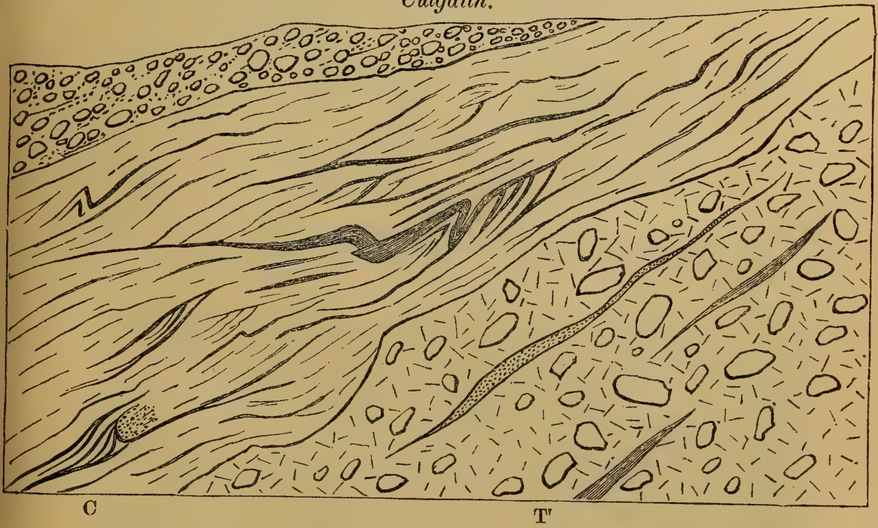
water. All the beds incline more or less towards the lower end of the valley; but some small sections at right angles to the axis of the drumlin show that the false-bedding planes slope outwards towards the sides of the drumlin as well. Fig. 3 shows a small section exposed by a slip of the beds nearly at right angles to the axis of the drumlin. The lowest beds seen were of till full of glaciated stones from the lower part of the basin of the Eden and from Galloway. Lines of sand, and lenticular patches of laminated gutta-percha clays, inclined at angles of about 30° towards the side of the drumlin, serve to mark the stratification in this bed. Lying upon the till, with an uneven line of junction, is a series of finely laminated striped clays, having a thickness of from 3 to 9 feet (fig. 4). The

Fig. 3.—*Section in the Settle and Carlisle Railway-cutting at Culgaith.*



Section at right angles to the axis of a drumlin. T. Upper till. S.G. Sand and gravel. C. Laminated clay. T'. Lower till. *r*. Rock. Length 40 ft.

Fig. 4.—*Section in the Settle and Carlisle Railway-cutting at Culgaith.*



Part of No. 3 on a larger scale, to show the irregular lamination of the clays in the drift. C. Laminated clays. T'. Lower till. Length 12 ft.

oblique lamination is very well marked in this; and the angle of inclination of the laminæ is nearly the same as that of the lines of clay and sand in the underlying till, and does not differ many degrees from the slope of the courses of sand in the overlying gravel series. It will be observed that the laminæ of the clay are bent over and inverted in a few instances, but that the apparently contorted parts are surrounded by other parts of the same deposit that are clearly not disturbed at all. This will be referred to again presently. Few or no stones are found in the clays, which seem to be made up of fine laminæ of clays of different shades of brown, and varying in lithological character from the finest clay to very fine micaceous sand. A clear section shows that these clays slope downwards to near the bottom of the railway-cutting, where a good section in them was to be seen at right angles to fig. 3. Figs. 5, 6, and 7 are taken from the bottom and the top of this deposit, as seen close to the rails. Figs. 5 and 6 exhibit the remarkably high inclination of the laminæ of the clays, and show in the most unmistakable way that this high inclination is the result of original deposition, as it does not in every case extend into the beds above and below. In the lower part of the section there is no indication of any derangement of the beds. Near the top, however, the case seems far otherwise; for the beds appear to have been subjected to violent pressure, which has contorted them in such a way that the same lamina may be passed through vertically three, four, or even six times in succession (fig. 7). A closer inspection shows that to a great extent this appearance is deceptive, and that the contorted beds lie in the

Fig. 5.—*Section in the Settle and Carlisle Railway-cutting at Culgaith.*

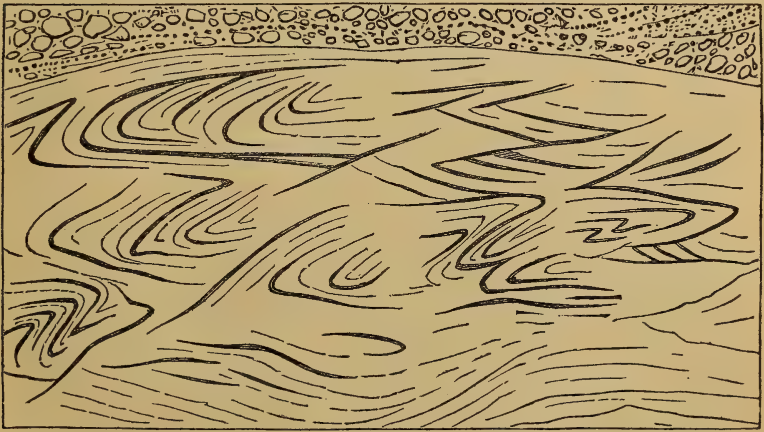
Alternations of inclined, arched, false-bedded and crumpled laminated clays with others undisturbed. The darker stripes represent the darker-coloured clays. Length 12 in.

midst of what are clearly undisturbed layers of clay, in many cases only a few inches off from the contortions.

Fig. 6.—*Section in the Settle and Carlisle Railway-cutting at Culgaith.*

Alternations of disturbed, false-bedded, and nearly horizontal laminated clays. All the lines represent the darker-coloured beds of clay. Length 9 in.

Fig. 7.—*Section in the Settle and Carlisle Railway-cutting at Culgaith.*



Laminated clays contorted, between undisturbed strata. Length 2 ft. 6 in.

Thinking there was something about these apparently contorted clays that could not be well accounted for by the ordinarily received theories of their origin, the writer paid much attention to their mode of occurrence, with the object of discovering something that would help to explain the difficulty. After noticing that most of the sections which showed contortions like those represented in fig. 7 were upon faces which run along the "strike" of the false bedding, and that along sections parallel with the lines of highest inclination the contortions are much simpler in character, the writer came to the conclusion that many of these apparent contortions may be due to the half-consolidated glacial mud slipping downwards to lower levels, and thereby causing a puckering of the beds. In this way certain parts of the clays must often have been thrown into sharp folds, and afterwards covered by laminæ that had not participated in the movement; so that it is easy in such a case as this to account for the occurrence of laminated clays bent into the most fantastic forms, and yet lying between perfectly horizontal layers of the same deposit. When such a series of strata is cut along a face nearly at right angles to the line of highest inclination, we should find the outcrops following sinuous lines which would impart an appearance of contortion to the deposit more or less marked in proportion to the amount of puckering the clays had undergone in slipping down the slope upon which they were deposited. In this way if any of the foldings bulged more in one part than in another, such a section-face as that mentioned above would show rudely ellipsoidal lines of outcrop one within another, in much the same way, to use a homely illustration, as the coatings of an onion appear when a slice is cut off the side of it. Although it is not supposed that this explanation will account for all the contortions in the clayey beds associated with the till, and still less for those in the Boulder-clays of the maritime districts, it will be at least worth while to bear it in mind in examining sections of what appear to be contorted clays elsewhere*.

The other beds in the cutting do not call for any particular mention, as they contain beds of laminated clays in every way like those just described; and the whole series, as before remarked, is overlapped by the stratified upper till, without any very clear line of demarcation between.

The first cutting north from Longwathby is through a tough maroon clay, containing a great variety of boulders up to 4 feet in diameter, including many from Galloway. Most of the stones are more or less waterworn; but the larger boulders retain a few scratches, and a few of the smaller are apparently as little rolled as those in ordinary till. The boulders are scattered throughout the clay without any indication of sorting, and the whole of the matrix shows faint traces of very irregular lamination, which is most evident on the freshly cut banks that have been washed by rain or by runlets of water from the top of the cutting. In this way the tougher laminæ are left in relief, and show some remarkable instances of curved lamination, though there is no trace of any thing like contortion in the cutting (fig. 8).

Another section, about a hundred yards or so to the north, shows beds of sand and gravel flanking the clay of the last-mentioned cutting, and overlapped by another clayey drift. What principally calls for notice in this section is the occurrence of undoubted instances of contortion on a small scale, apparently caused by the

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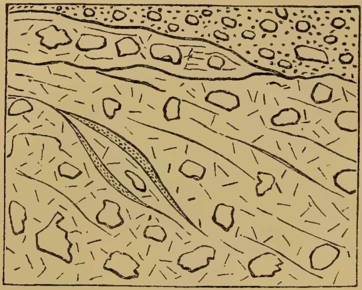
* Since the above was written I have stated my belief that these contortions are due, in great part, to the settling-down of the ice-sheet upon half-consolidated beds beneath. See 'Geol. Mag.' for Nov. 1874.

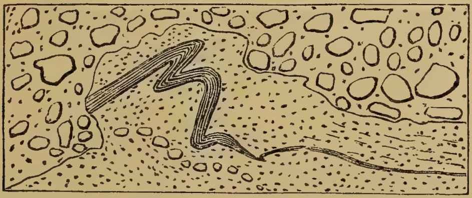
dropping of masses of coarse gravel into the soft beds of sand and loam beneath, so that the line of junction between the two deposits

Fig. 8—*Section in the Settle and Carlisle Railway-cutting at Longwathby.*



Gutta-percha clays and fine sand false-bedded in lower till. Length 3 ft.

Fig. 9.—*Section on the Settle and Carlisle Railway, near Longwathby.*

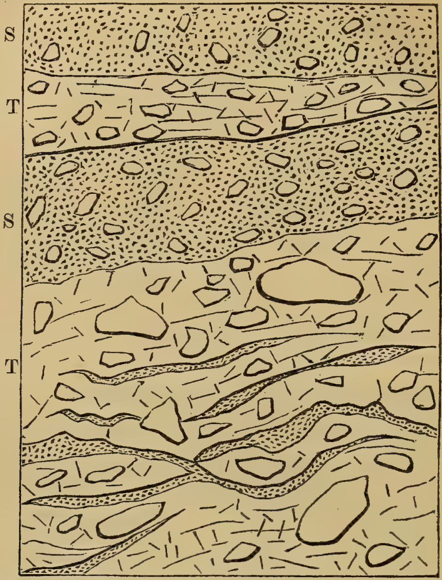


Contorted seam of loam in sand and gravel, unconformably overlain by coarser gravel. Horizontal length 6 ft.

of sand and gravel is very irregular (fig. 9). The false bedding is very marked in both these deposits; and the sheets of very clayey loam that occur seem, in a few instances, to follow the planes of false bedding, proving that they were originally thrown down on a slope.

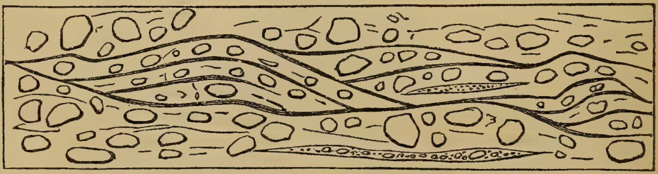
No section occurs nearer than about another mile to the north, near Little Salkeld, where there is a considerable thickness of alternations of gravels, beds of sand with occasional seams of loam, and thin partings of finely laminated clays without stones. Some of the clays are clearly disturbed where heaps of gravel have been thrown down upon them; but in other parts of the section that are apparently undisturbed, beds of obliquely laminated sands have partings of tough gutta-percha clays between the lamination-planes. The stones in the gravel are nearly all well washed and rounded; but an occasional one may be found retaining traces of striæ. At the northern end of this cutting maroon clays, like those at Longwathby, come up from beneath the sands and gravels. The clays alternate with lenticular patches of water-worn gravel, courses of sand, and thin sheets of laminated clays (fig. 10). Throughout the section the stones comprise a larger proportion of waterworn materials than may be found in the clay of the same kind at Longwathby. The lamination of the gutta-percha clays is very well marked, and seems to run in no well-defined general direction; it is frequently inclined at several degrees from the horizontal, and occurs in such a way that it cannot possibly be the result of any thing but original deposition. Fig. 11 will, perhaps, make this clear; it represents a length of about 4 feet of the stony clays of the cutting, over the

Fig. 10.—*Section in Throstle-Hall Cutting, Settle and Carlisle Railway.*



Intercalations of sand and gravel in till. T. Till. S. Sand and gravel. Length 6 ft.

Fig. 11.—*Section in Settle and Carlisle Railway-cutting at Throstle Hall.*



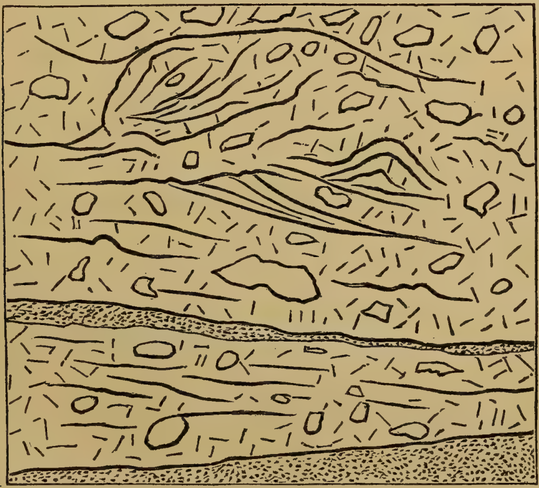
Gutta-percha clays in lower till. Length 4 ft.

nearly vertical face of which runlets of water had removed the more sandy parts, so that the tough clays stood out in relief as curved and inclined shelves. It should be observed that this appearance is not confined to one particular part of the cutting, but may be found over the whole length of it where the clayey beds come in (figs. 12, 13).

Fig. 12.—*Section in Settle and Carlisle Railway-cutting at Throstle Hall.*

Gutta-percha clays in lower till. Length 15 in.

Fig. 13.—*Section in Settle and Carlisle Railway-cutting at Throstle Hall.*



Irregularly stratified gutta-percha clays in lower till, with seams of soft sand. Length 4 ft.

The next cutting is about half a mile to the north, and shows sand and gravel-drift with loamy bands lying on a crushed surface of Permian sandstone. The loamy bands are inclined at various angles, and seem to have been moulded over the rock-fragments in one or two cases; but on the whole it is not clear whether the inclination is original or not. The section is principally remarkable for showing an apparent passage from undoubted glacial deposits, through crushed sandstone amongst the fragments of which the drift has been deposited, into unbroken rock.

Fig. 14.—*Section in Settle and Carlisle Railway-cutting near Armathwaite.*

Puckered beds of loam in loamy sand full of stones. Length 4 ft.

Near Lazonby a deep cutting has been opened about a mile and a half to the north of the one just mentioned. Here there is a considerable thickness of alternations of clean sand, beds of loam, and irregular deposits of gravel, throughout the whole of which washed stones occur. These beds seem to lie directly upon the rock in more than one part of the cutting. A few thin bands of loamy clay with traces of lamination occur at intervals; but no unequivocal indications of original inclination could be found in them. The loamy bands are slightly crumpled throughout the section, and seem to show, by the way the foldings match with those below and above, that some compressing force was exerted against the beds after they were laid down. A considerable length of sections shows plainly enough that the beds have not been disturbed to any greater degree than that indicated by the very slight crumplings of the bands of loam. The stones comprise much Permian sandstone, but no Brockram, a large percentage of Lake-country rocks and Carboniferous Limestone, and many stones from Galloway, as well as a few which Prof. Geikie says remind him much of the Lower Old Red Tuffs at the head of Nithsdale. As in other sections of a similar character, the stones are mostly waterworn; but they include a few that are quite angular, and an occasional one or two that have hardly lost any marks of glaciation. What is most noteworthy about the section is the close resemblance between this drift and the upper parts of the Upper Old Red in Birkbeck, between Tebay and Shap Wells, and its even closer resemblance to the highest beds of the Brockram series, as, for instance, in Hilton Beck and along the banks of the Bela. The resemblance is further increased by the prevailing red colour of the drift-deposit, caused by the large proportion of fragments of Permian rocks included in it.

Fig. 15.—*Section in Settle and Carlisle Railway-cutting near Armathwaite.*

Irregular seams of clay in stony loam. Length 3 ft.

The cuttings northward, at least as far as Armathwaite, are much of the same character as those just described (figs. 14 & 15). It is clear from an examination of them, that the proportion of waterworn materials steadily increases as we advance towards the Solway. Even the clays seem to pass into a loamy deposit, throughout which stones are scattered as they are in the clays; and the general impression left, after examining a long series of sections from the foot of Stainmoor very nearly to Carlisle, is, that the thin intercalated sands seen at the head of the valley swell out, the clays become more and more laminated and interbedded with sand and gravel, and ultimately pass into clean sands and gravels through such loamy deposits as occur about Armathwaite. Here and there in the low ground, beds like the till come in, and over- and underlie the sands and gravels in an irregular way; but there is a steady decline in the amount of clay as we go towards the north-west.

Much of this sand and gravel forms mounds which exactly answer the description of the Irish eskers, and, like them, show that the planes of false bedding incline the same way that the slopes of the eskers do. Some of the mounds are heaped up very irregularly, especially in places where, owing to the form of the ground, there must have been conflicting currents; so that here and there occur a few basin-shaped hollows, such as may be met with in mounds of drift of the same character in the Dale district.

Enough has, perhaps, been brought forward to show that there is a general agreement in the way in which the drifts come on in the Eden valley and the Dale district. In each case the lower till is mostly to be found in the bottoms of the valleys, not far removed from the head of the drainage-area; and the higher till is more angular, and contains, as a rule, less clay and fewer scratched stones than that below.

In each district the deposits of sand and gravel begin to come on in force at the points where the principal rivers of the area deliver a like volume of water; and from these points outward towards the mouths of the rivers, the total quantity of clay in the whole accumulation of drift steadily decreases until very little else than clean sand and gravel is to be found, except in the maritime districts, where the true boulder-clay comes on.

Each district affords proof that the clayey drumlins of the higher parts of the valleys pass into and form parts of the same series with the hummocky mounds and eskers of sand and gravel lower down, in such a way as to lead to the belief that they must have had a common origin.

Intercalated beds of sand and gravel and sheets of gutta-percha clays with curved lamination occur in the till of both districts; and all the evidence points to the conclusion that these intercalated beds have only undergone slight local derangement—and that it is the rule rather than the exception to find them quite undisturbed, except where the disturbance may be satisfactorily accounted for by the dropping of heavy masses of gravel, large boulders, or lumps of ice, or else by the settling-down of the ice-sheet upon the soft beds beneath.

The drumlins that include these intercalated beds of sand and gravel in the Dale district might possibly be accounted for as the moraines of the later glaciers of the ice-period; and therefore, in discussing the origin of these beds, it will be well to confine our attention to those drumlins at the foot of Stainmoor that, from their position, cannot by any possibility have had a morainic origin, but are, in all but the extraneous nature of the included stones, the exact counterparts of the Dale-district mounds, to which reference has been made.

The nature of the beds of till seen in Brough-Castle scar puts the marine origin of any one of them entirely out of the question. As at least seven or eight such beds occur interstratified with sand and gravel, it will be taken for granted that the intercalated beds also are not the result of marine action, but that the whole series is in some way the result of some other and frequently recurring cause. The stiff clay full of blunted and scratched stones of all sizes up to 4 feet, disposed without any regard to form or size, cannot be any thing else than the work of ice: but when we try to explain the presence of seven or eight, or, in some cases, as many as eleven such beds of till interstratified with undisurbed beds of sand and finely laminated clays by the *moraine-profonde* theory, as it is usually (and so far as the writer can gather from the latest books treating of the subject) universally understood, we meet with complete failure.

It does very well in cases where we have only to account for the origin of an unstratified mass of stiff clay full of glaciated stones whose longer axes are nearly parallel to the underlying rock-surface. It is at least intelligible how a mass of ice which, at the foot of Stainmoor, was certainly not less than 1200 or 1400 feet in thickness, could cause to accumulate here and there beneath it thin deposits of tough clay and scratched stones which had been scraped along between the ice and the rock-surface for many miles. But if any one nowadays needs to be convinced of the power of such a sheet of ice to crush up and contort any soft beds that lay in its way, let him examine a few sections of alternations of hard and soft beds that have lately been bared of drift, at almost any spot over which the ice had a great thickness; it will then be manifest that these thin soft beds of sand and clay occurring interstratified with the till, could not have escaped violent contortion. They would be much more likely to be kneaded up into the clays until every trace of their existence was lost, if the ice ever advanced a single inch over them.

It was mentioned above, that the far-derived boulders had hitherto been met with only in the upper till, or in deposits that are probably referable to that horizon. Taking it for granted that the ice that transported the Galloway boulders right across England to the North Sea, and exercised enough denuding force to tear up Brockram from the bottom of the valley of the Eden, and afterwards transported it up the slopes of Stainmoor, must, if the *moraine-profonde* theory be entirely true, have had a much greater thickness than the ice that was only capable of dragging its *moraine profonde* a few miles; it follows that it must have tended, more than the hypothetical older ice-sheets, to crush and contort every thing that could be thus acted upon from the surface. How then can we account for the presence of entirely undisturbed beds of finely stratified and incoherent sands, and sheets of laminated clays in and beneath the upper till?

As the *moraine-profonde* theory fails to meet the requirements of these cases, it is obvious that some other explanation, which shall be more in accordance with the observed facts, must be looked for.

The writer therefore ventures to lay before the Society a theory that has suggested itself after a long consideration of Prof. Ramsay's theory of Glacial currents, and a careful examination of a considerable tract of country in the north-west of England by the light of this theory.

Most persons who have lately written on glacial subjects have remarked how suddenly the great ice-period was brought to a close. So little modification have the striæ undergone at almost all elevations, that it is no uncommon thing to find the striæ going right across the bed of a considerable valley in such a way as to show that, had the ice dwindled away by slow degrees, and passed back through all the stages of glacier-development to the tiny glaciers of the later period, all traces of the former existence of the great ice-sheet must have been obliterated from the low ground. Everywhere the ice appears as if, after it had reached its maximum thickness, it had quietly melted away, without the lower part, at any stage of its liquefaction, ever again advancing over the rock.

Another point that many recent authors seem agreed upon, but that is not so well borne out by the facts observed in the district treated of in this paper, is that the till is largely, perhaps almost entirely, made up of detritus scraped from the rocky bed over which the ice was passing—that the till was brought into existence underneath the ice, and there it was kept until the ice melted.

Prof. Ramsay's theory of Glacial currents enables us to go a step further than this in treating of the origin of drift deposits.

We can see that one of the results of such crossing currents would be that streams of ice from subsidiary valleys would frequently keep the level at which they blended with the main stream for some distance from the valley wherein the lesser stream originated, and that, in the numerous cases in which the upper parts of the ice filling a valley were crossing it at various angles according to local circumstances, much of the débris from the lee side of the valley would be swept into the traversed current and transported to the main stream, where these lateral moraines would be intermingled with others derived in a similar way from rocks afar off. What was there to cause the bottom layers, or, indeed, any part of a tributary ice-stream, to pass at once into the lowest part of the main stream, which in no small number of cases must have been flowing in quite a different direction from that of its feeder? Take the case, for instance, of the local ice coming from the Cross-Fell district to join the Eden-valley stream. The directions taken by the main stream and its affluents must have often approached a right angle; and the level at which the local ice blended with the larger stream must often have been several hundred, or even, in some cases, a thousand feet above the bottom of the Eden-valley ice. The behaviour of no modern glacier would warrant us in concluding that, in this and the innumerable similar cases that might be cited, the high-level ice, with its load of boulders, would at once, or at all, work down to the bottom of the main stream.

It would be easy to point to many similar cases where the direction of the higher glaciation was often at considerable angles with that of the adjoining lower ice over which it would pass.

In this way it is quite possible that boulders might be transported across wide valleys without ever reaching the bottom of the ice there, so that the transport of Shap-granite boulders is not difficult to understand when the existence of a great uptravelling mass of ice is clearly proved.

The frequent deflections of each stratum caused by the inflowing of large feeders and the varying form of the rocky bed and the sides of the valley along which the ice was passing, must have contributed in a great degree to that intermingling of boulders derived from widely parted sources that is one of the most noticeable phenomena in any section of far-derived drift. There seems, too, to be some reason for thinking that this intermingling would be still further brought about by the occasional upforcing of some of the strata of the ice-sheet in places where, so to speak, the ice was closely hemmed in on all sides, as it must have been at the foot of Stainmoor.

When the great ice-sheet began to melt, the stones that were nearest the bottom of the ice, and which, from their position, must have undergone the greatest amount of glaciation, began to be deposited on the floor of glaciated rock, or on patches of the true *moraine profonde*, where these existed. The water resulting from the melting of the bottom ice would find its way here and there towards the sea along channels in the slowly thickening deposit of till. Where such ridges of rock existed as resulted from the unequal wear of hard and soft beds, the water would be more likely to flow along the intervening hollows than to pass along or across the higher ridges; so that in this way it must often have happened that the deposition of till went on over preexisting rock-ridges, while the intervening hollows were kept clear by the water that flowed in them. It is obvious that the further the point from the head of the valley the greater would be the quantity of water flowing beneath the ice. It should be borne in mind that there would be not only the water resulting from the melting of a great thickness of ice, but the rainfall of the period to be carried off in some way towards the sea. We can therefore understand how it is that the drift-materials that were slowly melting out of the ice sheet, became more and more waterworn in proportion to the distance from the head of the valley. As the currents shifted they must have allowed till to accumulate in parts where previously nothing but sand and gravel had been laid down; while, on the other hand, they must frequently have cut into banks of till, and afterwards filled the denuded hollows with waterworn materials as their course slowly changed. In this way there can be little doubt that the drift in the lower parts of the Eden valley must frequently have been removed soon after deposition, and the materials re-sorted and further waterworn, and afterwards redistributed in some protected spot further down the valley.

Here and there waterworn materials must have found their way down through crevasses to the bottom of the ice, so that nests of undisturbed sand and occasional patches of gravel would accumulate where, for some distance around, nothing but till was being left by the ice. In the quiet spots amongst the till, out of the reach of the subglacial streams, runlets of water charged with fine glacial mud must have flowed over the irregularities of the till, depositing sheet upon sheet of fine clay until some of the inclined sheets of gutta-percha clays were accumulated. It would be very difficult to give any satisfactory explanation of their origin besides the one here advanced. If the clays were deposited under water, they would not fail to be spread out in perfectly horizontal sheets; at any rate it is quite impossible that they could be thrown down at angles of from

15° to 30°, as are many in the Longwathby cuttings and elsewhere. Nor will any other explanation yet given make it clear how these laminated and exceedingly fine clays could be accumulated while big and little stones were being dropped into the soft clays below to such an extent that some of the gutta-percha clays gradually pass into good characteristic till.

It cannot be doubted that fragments of ice would now and then fall into the soft drifts, contorting the beds some little distance around, and that, as Sir Charles Lyell has remarked, the detritus that accumulated around these lumps of ice would be thrown down in great confusion when the ice melted. Add to this the occasional local contortion caused by the falling of large boulders, the heaping up of masses of coarse gravel upon unconsolidated beds of sand and mud, the slipping forward of soft beds deposited on a slope, and the occasional movement of the slowly melting sheet of ice, and we can see that there is no occasion to call in the agency of floating ice to account for any amount of local contortion which the beds may have undergone.

In the maritime districts beyond the edge of the ice it is not at all unlikely that floating ice was at work contorting the beds; but as Mr. Geikie has lately remarked that the importance of floating ice as a boulder-transporting agent has been greatly overestimated in dealing with the British drifts, it is not at all unlikely that what has been set down unhesitatingly as contortion caused by floating ice may, in a few cases, have been in reality due to some of the causes enumerated above.

In the higher parts of the valleys, where the quantity of water flowing beneath the ice was less than elsewhere, there would be little or no denudation or water-wearing of the drift going on; so that in such places the accumulation of till must have gone on almost uninterruptedly until no more ice was left. In this way those sloping banks and plains of till that occur high up near the watersheds must have been formed.

The boulders in the upper parts of the ice, which in a great many cases must have been those that had travelled furthest, would, as Mr. Geikie has remarked, often be stranded at high levels as the ice melted; but if the theory here put forward be true, this deposition of the highest boulders must in the majority of cases have been the last work of any given part of the ice-sheet; so that while till and gravel were being accumulated at low levels, the deposition of the higher-lying boulders was going on; and it was not until the ice was nearly all melted, and therefore the greater part of the mounds of till and of the eskers was heaped up, that the higher parts of the ice-sheet, with their load of far-travelled and often angular boulders, would be left as traces of the last work of the waning ice-sheet.

It should, however, be mentioned that in the Eden valley and in the Dale district there are no more boulders *on* the Eskers and drumlins than occur in sections of those drifts of the same area; in other words, boulders are quite as common *in* the eskers as they are on their outsides.

Before concluding, it will perhaps be well to refer to one or two other glacial phenomena this theory of the origin of drift seems to throw light upon.

In many places in the Dale district, beyond a radius of ten or twelve miles from the principal centre of dispersal of the ice, great heaps and ridges of unstratified drift, with very little clay and almost no scratched stones, but charged throughout with angular blocks, occur here and there on the higher ground. It seems mostly to lie on the lee side of prominent ridges which the ice must have swept over at the time when it attained its greatest thickness. Most of it has a very morainic look, which is rendered still more striking by the irregularly moundy character of its surface. As a rule, the included blocks seem to indicate that the bulk of the drift was derived from the higher-lying rocks of the district, fragments of beds below the upper division of the dale-rocks being seldom met with. Had it not been that these highest beds referred to are largely made up of shales and soft beds of a similar nature, to the extent of fully half the whole bulk of the rocks, the origin of these mounds could have been easily enough accounted for; but the absence of any noticeable proportion of clay or of shale-fragments renders it extremely unlikely that the moundy-surfaced drift represents either the lateral or the terminal moraine of any part of the great ice sheet as it receded up the dales. The detritus scraped off from ridges that the ice was crossing at high levels must very frequently have found its way into the main stream at nearly the same level, and, as a consequence, must very rarely have got low enough to undergo any great amount of glaciation by being forced over other high-lying rocky surfaces that might help to round and scratch any of the blocks imbedded in the ice. All the soft beds that entered the ice along with the harder blocks would soon be either decomposed or crushed into clay, which would sooner find its way to the bottom of the ice than any of the stones that entered with it. A sheet of ice charged in this way must always have had the greatest proportion of worn stones and clay near its base, and the most angular and least clayey detritus at the top. When such a sheet of ice flowed across many valleys, it can hardly be doubted that in the majority of cases it was the upper part only of the ice that would cross the next opposing ridge; and in this way the materials of the till would be sorted out again and again from the angular drift. As the ice melted, it deposited this angular drift in exactly the same way as it did the till at lower levels, the difference being that in the case of this moraine-like drift little or no clay and hardly any scratched stones were imbedded in the ice to be deposited along with the angular drift, while nearly all the clay was left in the till.

The heaping-up of masses of drift at the main-valley end of the dividing ridge between two tributary dales, pointed out in Mr. Dakyns's paper "On the Glacial Phenomena of the Yorkshire Uplands"*, is to be accounted for in the same way as the shaping of the drumlins. The water resulting from the melting of the ice must

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* Quart. Journ. Geol. Soc. vol. xxviii. (1872) p. 384.

have flowed very nearly along the present course of the stream at the bottom of the valley; so that the deposition of drift over the ridge intervening between the two dales went on in many cases uninterruptedly from the first melting of the ice until it was all gone, while at lower levels the stream would be continually transporting the drift-materials towards the end of the dale as fast as they melted out of the ice.

There is one more point to which it will be well to call attention, although it relates to a district far from that which is here treated of. There has been some difficulty in accounting for the absence of much drift on the eastern slopes of the Pennine chain at some distance to the south of the Dale district. May not this be due to the fact that on the eastern side of England there was no great centre of ice-dispersal in the relative position of the Lake district, the general form of which caused the Dale-district ice to be pressed close up to the western side of the Pennine chain? It is far from unlikely that the crescentic group of high fells ranging from High Seat to the south of Coniston Old Man caused a south-easterly current to flow at a high level over the low ground between Kendal and Kirkby Lonsdale. Such a current could hardly have been without its influence upon the course taken by the upper parts of the Dale-district ice, and it must have helped very materially to keep them pressed against the western side of the Pennine chain. On the eastern side there is no evidence of any such current; and the ice there, instead of flowing close to the high ground as it did on the west, seems to have gone away steadily in a south-easterly direction towards the North Sea.

Conclusion.

The principal conclusions, therefore, which have been drawn from the facts detailed in the foregoing pages are the following:—

The whole of the district treated of in the paper was once enveloped in a part of the great ice sheet whose existence in adjoining districts has been demonstrated by Messrs. Tiddeman and Ward.

There seems evidence to prove that the upper limit of this part of the ice sheet stood somewhere between 2200 and 2400 feet above the present sea-level, at the points where the ice sheet attained its greatest thickness.

A line of ice sheet extended nearly along the present watershed of the Lake district to the highest ground in the Yorkshire dales. To the south of this line the ice at high levels flowed straight away over the fells into Lancashire and West Yorkshire; while that to the north, after flowing a short distance into the Eden valley, was turned to the east, and compelled to flow over Stainmoor towards the North Sea.

Some evidence has been given to prove that few even of the smaller valleys could have been the work of ice, but that, on the contrary, the ice seems to have tended rather to level the minor inequalities of the surface, and thus to efface the smaller valleys.

Dangerfield, Lith, 22, Bedford St: Covent Garden.

MAP
to illustrate the
GLACIAL PHENOMENA OF THE EDEN VALLEY, &c

Dangerfield, Lith, 22 Bedford St. Covent Garden

It has also been shown that much of the surface-configuration that is characteristic of the Dale district has been due to glacial erosion—and that, as a perfect gradation in form may be traced from the straight lines of scar, which it seems impossible to refer to any other than glacial origin, to the crescentic scars that have all the characteristics of cirques, these also have originated through glacial erosion.

In treating of the origin of drift, the principal conclusions are, that the facts observed are irreconcilable with either the *moraine-profonde* or the marine theory—and that the angular moraine-like drift occasionally found in parts of the dales, the upper and lower tills and the intercalated beds, the deposits of sand and gravel that form the eskers, and, finally, the numerous boulders that are left at nearly all elevations are each and all the results of the melting of a great sheet of land ice that was charged throughout with rock-fragments of all sizes and of all the kinds occurring within the area wherein the ice originated.

Lastly, the present unmodified form of the drumlins and eskers, the entire absence of any thing like a terrace of marine origin, and the difficulty of pointing to any case of boulder-dispersal in directions that glacial currents may not have taken—all seem to prove that, whatever submergence followed the climax of the glacial period, most of the existing glacial phenomena are the work only of the ice sheet. So little, indeed, has the aspect of the country changed in Postglacial times that in many places the larger rivers are even now above the bases of the adjoining drift-mounds, whose present form can hardly be referred to any other than glacial action; and Postglacial denudation generally has effected so little that by far the greater part of the present surface-configuration has, in one way or another, resulted from the former presence of the great ice sheet.

EXPLANATION OF PLATE II.

Map to illustrate the Glacial Phenomena of the Eden Valley and Yorkshire-dale district.

4. *On* Fossil Evidences *of a* Sirenian Mammal (*Eotherium ægyptiacum,* Owen) *from the* Nummulitic Eocene *of the* Mokattam Cliffs, *near* Cairo. By Prof. Owen, C.B., F.R.S., F.G.S., &c. (Read November 18, 1874.)

[Plate III.]

The evidence of the Sirenian mammal now submitted to the Society is from the white, compact, fine-grained, calcareous stone of the Nummulitic Eocene Tertiary period, now quarried extensively in the Mokattam cliffs, south of Cairo, for the buildings in progress in the modern part of that city.

The block of stone containing the fossil was shown and afterwards presented to me by Dr. Grant, an eminent practitioner in Cairo, who possesses a good illustrative collection of fossil shells from the above formation; but the appearances of the exposed parts of the present fossil were, as may well be supposed, both new and strange. That the block contained the cast of some organic cavity was the best interpretation I could, at first sight, offer; and the subsequent clearing away of the matrix determined the fossil to be part of the cranium, with a cast of its interior representing the brain, of a species of Sirenian mammal.

The portions of the skull preserved are scanty; they include parts of the basioccipital, basisphenoid, and petrosals. The bodies of the two cranial vertebræ have not coalesced, but show the flat, vertical, roughish syndesmotic surface, which long remains in the recent Dugongs* and Manatees †. The alisphenoids are confluent with the basisphenoid; and the line of union is impressed, on the inner or cranial surface, by the large trigeminal nerve.

These portions of cranial bones have the dense texture characteristic of the Sirenian skeleton. The petrosals, of a deeper tint, show an almost crystalline fracture, yielding at least a compact polished surface. The preserved part of the basioccipital is the fore one, where it gains vertical thickness, with a small part of the hind flatter portion, the rest being broken away from the expansion to join the condyloid parts of the exoccipital; so much as remains shows the extent of the free lateral surface contributing to the large vacuity in the cranial walls, in which the petrotympanic bones are loosely suspended.

The cast, as finally worked out, includes the entire brain and the beginning of the myelon (Plate III. figs. 1–4). This cast bears about the same proportion to that of the cranial cavity of the existing Manatee (fig. 5) as does the cast of the cranial cavity of the Anoplothere‡ to the brain of a modern ruminant of the same size as that ex-

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* See Home, Phil. Trans. 1820, p. 154, pl. xiii. fig. 1.

† Vrolik, Bijdragen tot de natuur. &c., Kennis van den *Manatus americanus* (fol., 1852), vierde Plaat, fig. 12, *b*, *c*.

‡ Cuvier, 'Ossemens Fossiles,' tom. iii. (4to, 1822), pl. vii. fig. 3, p. 44. E. Lartet, "De quelques cas de progression organique vérifiables dans la succession des temps géologiques sur des mammifères de même famille et de même genre."—'Comptes Rendus de l'Acad. des Sciences,' Paris, 1er Juin, 1868.

tinct Artiodactyle; and, as in the latter comparison, the defect of cerebral development in the Eocene prototype is more in regard to breadth and depth than to length of brain.

The supporting floor of the macromyelon is bounded anteriorly in *Manatus* by a shallow transverse linear depression, about one line behind the "sella;" its length from the lower margin of the foramen magnum is 1 inch 8 lines.

A transverse ridge *r* (Pl. III. fig. 3), crossing behind the swelling representing the infundibulum (*p*) in the cast of the cranial cavity of *Eotherium*, has filled a similar but deeper transverse groove, and marks the anterior limit of the macromyelon in the Eocene Sirenian. From this mark to the hind fracture, which appears to have taken place just beyond the foramen magnum, the length of the macromyelon may be taken at 1 inch 9 lines.

The median mass *b* (Pl. III. fig. 3) indicates the enlarged anterior myelonal columns; they are defined by a shallow depression from the lateral or "restiform" columns (*x*). The "pons Varolii" is indicated at *a*. A depression (*c*, fig. 2) on each side the posterior or dorsal surface of the macromyelon indicates the limit between the posterior myelonal columns and the post-restiform tracts. The section of the macromyelon at the foramen magnum is shown in fig. 4. It is broader than it is deep, but rather less so than in *Manatus*. The cast of the cranial cavity in this Sirenian, showing the brain as covered by its membranes (fig. 5), indicates the prominence of the pons Varolii as feebly as in the fossil. The size of the cerebellum is marked in a greater degree in such casts than is that of the pons. The median series of folds, or 'upper vermiform process,' makes a slight prominence in the fossil (fig. 2, *v*); but the relative size of the cerebellum to the cerebrum is characteristically small, as in the existing Sirenia (fig. 5, *v*). The breadth of the epencephalic chamber, as represented by the cast, is 2 inches: there is a slight contraction between this and the prosencephalic chamber, which soon swells out to a breadth of 2 inches 4 lines; this gives the extreme breadth of the cerebrum in *Eotherium*. The length of the cerebrum is 2 inches 6 lines; the breadth of the anterior lobes is 2 inches. The prominence anterior to the Sylvian fissure (figs. 1 & 5, 5), answering to that marked *n* in pl. xxv. fig. 32, Zool. Trans. vol. viii., is recognizable in the fossil. The upper and lateral surfaces of the casts (figs. 1 & 2) indicate the coarse fibrous character of the dura mater, such as this membrane shows in recent Sirenians. The pedicle of the pituitary body is marked by a small prominence (fig. 3, *p*) anterior to that indicating the infundibulum. On each side of this part the optic nerves (*o o*) are indicated, converging as they advance. External to the optic nerves are the large trigeminal ones (*tr*), of which about an inch and a quarter remain, with a thickness, as covered by the dura mater, of 4½ lines. The rhinencephala (olfactory bulbs) are of moderate size (figs. 1–3, R). The depression dividing the hemispheres above is rather wide along the mid line; a narrow ridge of the cast along the fore half of this line indicates a depression for the insertion of the falx (fig. 2, *f*).

The brain in existing Sirenia is characterized by a subquadrate form of the cerebrum, with the angles rounded off, arising from the breadth of the fore part being equal, or nearly so, to the hind part, the cerebrum not gaining, or but slightly gaining, breadth (*Manatus*), or slightly losing breadth (*Halicore*), as it recedes or approaches the cerebellum. The first character is exemplified in the figures of the brain, or its model, of the American Manatee (*Manatus americanus*, Cuv.), given by Murie *. But the proportion of breadth to length is less in the Eocene fossil.

As the figures by Murie represent the brain of the Manatee uncovered by its membranes, I have taken a cast of the interior of the cranial cavity of a full-sized *Manatus americanus* to compare with the appearances presented by the fossil, and have figured the upper surface in Pl. III. fig. 5, and the under surface of the cerebrum and rhinencephalon in fig. 6, of the natural size †.

In the Manatee (*Manatus americanus*) the greatest breadth of the parietal roof of the cranial cavity is four tenths of the total length of the skull ‡; in the *Rhytina* it is a little more than two tenths of that length §; in *Halitherium* it is rather less than two tenths. *Halitherium* and *Manatus* give the two known extremes in the proportions of the breadth of the cranial cavity to the length of that cavity and of the entire skull in Sirenia. The proportions of the brain correspond with those of its bony case. This is exemplified by those of the brain of the Dugong ||, the proportions of the cranial cavity of which are intermediate between those of *Manatus* and *Rhytina*. The proportions as to breadth and length of the brain of the extinct Sirenian of the Eocene of Egypt are those of *Halitherium*. From the shape of the brain-case in *Felsinotherium Forrestii*, as shown in tav. ii. of Capellini's admirable memoir on that Sirenian ¶, I infer that the shape of the brain must have been much more nearly that of the cast from *Eotherium* than is the cast of the brain-case in the recent Manatee.

The above considerations and comparisons will, I trust, beget the same conviction as with myself, that a Sirenian mammal near akin to *Felsinotherium*, Cap., to *Halitherium*, Kaup, and *Metaxitherium*, Christol and Gervais, existed in the seas in which the calcareous nummulitic Eocene stone of the Arabian cliffs was deposited **; whence the inference may be drawn that such formation was accumulated at no great distance from the shore. It is an extreme sup-

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* Trans. Zool. Soc. vol. viii. pl. xxv. figs. 31 & 33. "A cast of the cranial cavity, with its enclosed dura mater, was subsequently made; and by the help of this cast and the shrunken brain the sketches (pl. xxv.) were drawn" (p. 181).

† A figure of such cast, of half the natural size, is given by Brandt in his 'Symbolæ Sirenologicæ,' t. ix. fig. 1.

‡ Vrolik, 'Bijdragen tot de natuur. &c., Kennis van den *Manatus americanus*' (fol. Amsterdam, 1852), vierde Plaat, fig. 11.

§ Von Nordmann, 'Beiträge zur Kenntniss des Knochenbaues der *Rhytina Stelleri*,' 4to, Helsingfors, 1861.

|| Brandt, 'Symbolæ Sirenologicæ' (4to, 1861–8), t. ix. fig. 2, Taf. i. fig. 1.

¶ Memorie della R. Accademia delle Scienze dell' Istituto di Bologna, Serie terza, tomo i. p. 605, tav. i.–viii. (1872).

** A Dugong (*Halicore tabernaculi*, Rupp.) still exists in the Red Sea.

position that the carcass of a dead Sea-cow should be caught by a current and carried very far out to sea before it sank and became imbedded.

That more of the skeleton of this Sirenian should not have been recovered is due to the entire absence of any care or attention to such appearances on the part of the native workmen, who break up the matrix into small pieces for their modern rubbly method of construction. The happy accident of Dr. Grant's attention being attracted to one of these bits led to the acquisition of the subject of the present communication. My own repeated search of the quarries and quarried material was repaid by the acquisition of other fossils not before noticed, and which I may at another Meeting bring before the Society. My friend Dr. Grant has promised to transmit any teeth or portions of bone in the same stone which may appear to have belonged to the animal or species to which I refer the natural model of the brain.

The fine-grained white calcareous stone, quarried of old to an enormous extent from Mokattam to Toorah (some of the old detached colossal blocks being picked at, as it seems, by a race of pygmies, comparatively, at the present day), overlies the strata forming the base of the cliff, of yellowish limestone, containing fossils of *Callianassa, Nerita conoidea, Periaster obesus, Alveolina oblonga, Nummulites planulatus*, &c.

With the *Eotherium* were associated *Conoclypeus Flemmingii, Nautilus Labechii*, D'Arch., *Nautilus Forbesii*, D'Arch., fine casts of *Cerithium giganteum*, of *Turbo*, of *Rostellaria*, of *Cyprina*; not a few of my fossils are well-preserved specimens of *Lobocarcinus*, nearly allied to, if not identical with, *L. Paulino-Wurtemburgensis*, Reuss and von Meyer,—all testifying to the Eocene period of its deposition.

This white calcareous zone, of immense thickness at some parts, is overlain by Miocene strata, with *Clypeaster ægyptiacus, Pecten aduncus*, teeth of *Carcharodon*, numerous *Ostreæ* and *Placunæ*. From these deposits have been derived the far-scattered petrified wood, from my gatherings of which Mr. Carruthers has determined two species of *Nicolia* *.

The exposed surface of these strata presents a reddish tinge. A detached, outlying mass, on the way to the "petrified forest," takes its name "Jebel Achmar" (red hill) from the red quartzose material which predominates therein.

The Sirenians present so singular and extreme modifications of the mammalian type that one is specially moved to ascertain at what period it was first manifested. I regret that I have not been able to obtain evidences of the geological zone or age of the "red conglomerate and sandstone forming the river-course" near "Freeman's Hall, Jamaica," where the fossil skull of, to my knowledge, the least-modified of Sirenian forms was obtained †. All that I could learn from its discoverer was that this river-bed was "overlain by limestone, differing from the general Tertiary carious limestone of the island" ‡.

Eotherium, as exemplified by the brain-cast, is of Eocene age, of

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* Geological Magazine, vol. vii. p. 306 (1870).

† Proceedings of the Geological Society, June 13, 1855, p. 541.

‡ *Ibid.*

the Cerithian-nummulitic zone, and consequently older than any other known genus of extinct Sirenians whose bed has been geologically determined.

The first discovered Sirenian fossils, referred to a *Hippopotamus minor* and to a *Manatus fossilis* by Cuvier (the *Manatus Guettardi*, De Blainville), are from French tertiaries of Miocene age. The Sirenian first generically separated from living forms, by Kaup, under the name *Halitherium*, is from the Miocene of Eppelsheim, near Darmstadt. The *Halitherium Serresii*, Gervais (*Metaxitherium*, De Christol), is a Miocene fossil *; and Sirenian fossils have been traced in France from the "calcaire grossier" of the Gironde, containing Lophiodont remains, up to the Pliocene near Montpellier. *Crassitherium robustum*, Van Beneden, is from a formation of Lower Miocene age in Belgium, the equivalent probably of our Hempstead beds †.

Felsinotherium Forrestii, Capellini, is from beds at Riosto, in Bologna, regarded by that excellent observer as of Pliocene age ‡.

The Sirenian fossils (*Rytiodus*, Lartet) from the basin of the Garonne, are from Upper Miocene beds §. Prestwich considers the native matrix of the "*Halitherium Canhami*, Flower," to have been "most likely derived from some Miocene beds which formerly existed, probably in what is now the basin of the German Ocean" ‖.

Dr. Leith Adams has recorded "the discovery of a tooth and ear-bone of a *Halitherium* in a calcareous bed at Malta" ¶. The *Rhytina Stelleri*, Illig. (*Manatus borealis*, Pall.), "ce trop confiant Sirénien de l'île Behring," lived on the North Pacific Ocean to within the last century.

We have thus evidence of an almost world-wide distribution of Sirenian Mammals, under several generic modifications, which has become restricted at the present date to a few tropical or subtropical localities, under the forms signified by the terms *Manatus* and *Halicore*.

In both Lamantins and Dugongs the cerebrum is better developed than it was in *Rhytina*, and in *Rhytina* somewhat better than in *Eotherium*. In the recently extinct Sirenian the excess is at the back part of the cerebrum **; in *Halicore* it is at the fore part. In *Manatus* both fore and hind parts of the hemispheres are relatively broader and higher than in the extinct Eocene form.

Viewing fig. 2 in contrast with fig. 5, one is led to speculate on the circumstances influencing increase of brain-mass in marine Mammals of simple, sluggish, Sirenian habits, either obtaining their food from seaweed at no great depth, or shuffling along to browse the grassy shore of a river or estuary. Certain it is that since the good

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* 'Zoologie et Paléontologie Françaises' (4to, 1849), Descr. des Pls. 4, 5, 6.

† "Un Sirenien nouveau du terrain rupelien," Bulletin de l'Acad. R. de Belgique, 2^e série, tom. xxxii. 1871.

‡ "Deposito littorale pliocenico di Riosto, litologicamente non solo ma eziandio per i fossili e per i rapporti stratigrafici col cretaceo ed il mioceno," Memorie della R. Accademia delle Scienze dell' Istituto di Bologna, 4to, serie terza, tomo i. p. 609.

§ "Note sur deux nouveaux Siréniens fossiles des terrains tertiares du bassin de la Garonne," Bulletin de la Soc. Géol. de France, 2^e série, tom. xxiii. 1866.

‖ Quart. Journ. Geol. Soc. vol. xxx. (1874) p. 7.

¶ *Ibid.*

** Brandt, *op. cit.* t. ix. fig. 3.

Fig: 5.

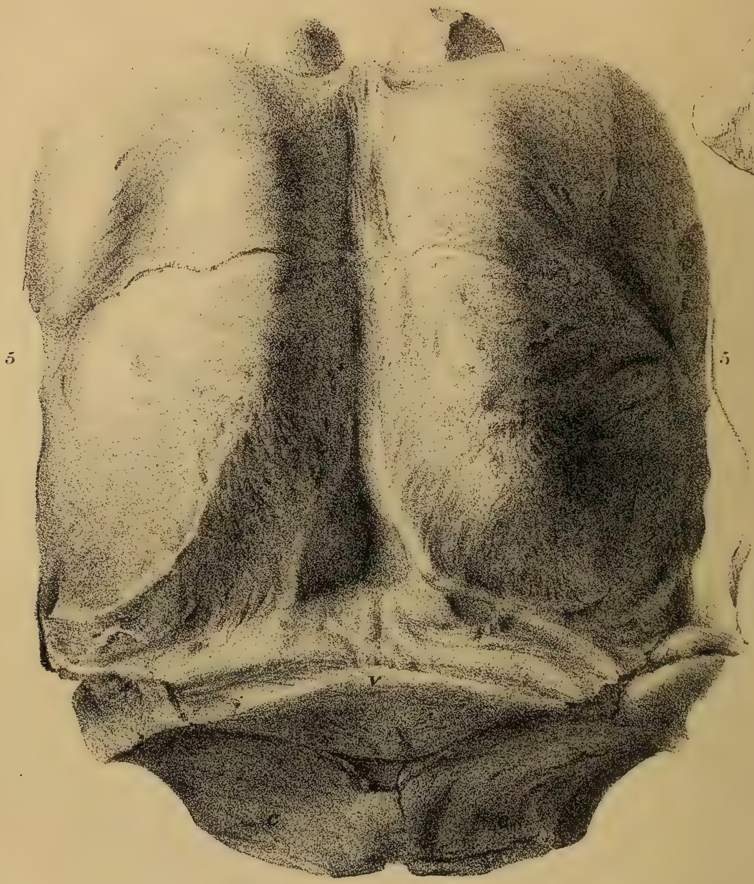


Fig. 6.

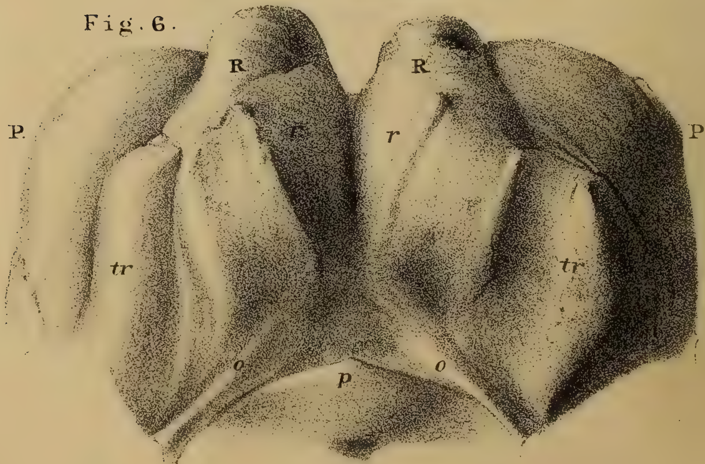


Fig:

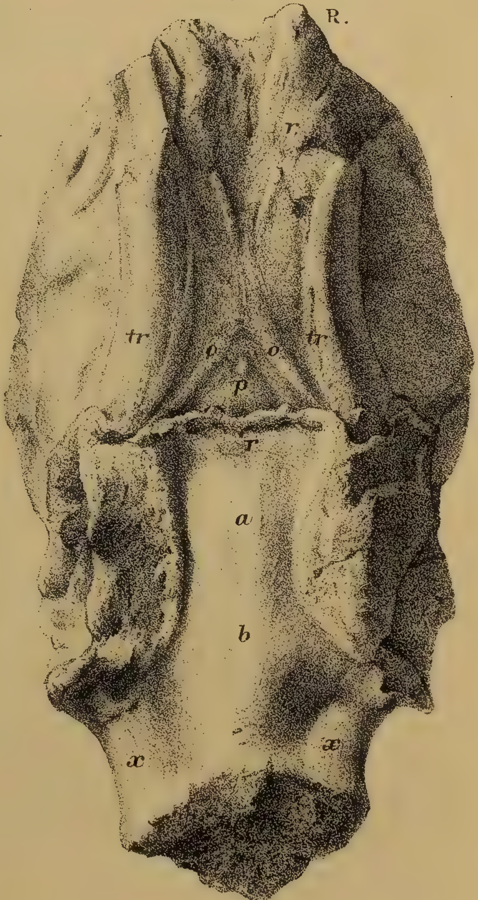
G.H.Ford del. C.L.Griesbach lith.

CASTS OF BRAIN OF EO

Fig: 1.

Fig. 2.

Fig: 3.



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RIUM AND MANATUS.

Fig 5.

Fig 4.

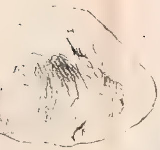


Fig: 1.

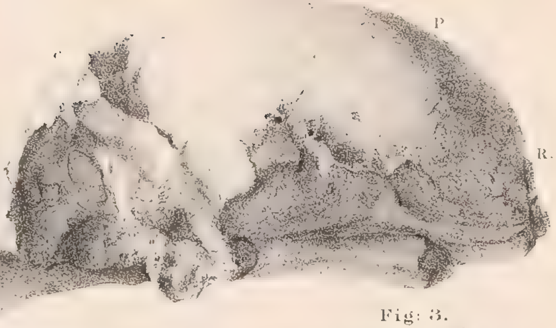


Fig. 6

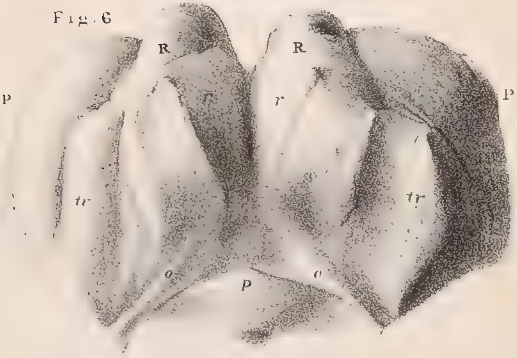
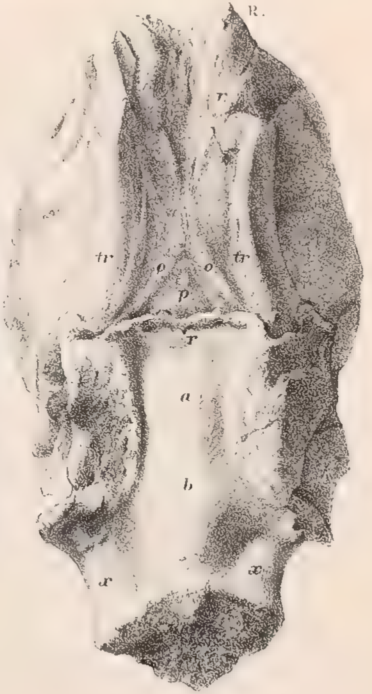


Fig. 2.

Fig: 3.



G.H. Ford del. C.L. Griesbach lith.

Mintern Bros imp.

CASTS OF BRAIN OF EOTHERIUM AND MANATUS

old Eocene times "new foes have arisen;" and any increase in the number of creatures and their lethal powers concerned in killing sea-cows would add to the number of phenomena which such sea-cows were concerned in noting, with concomitant reaction of such perceptions, or neural vibrations, resulting in a change of cerebral into muscular force, exercised to put themselves into depths of safety. With such augmentation of ideas, *i. e.* of sensations and volitions, in surviving modern Sirenians, the thinking organ has grown; and this hypothesis or explanation may apply to analogous instances in other time-series of herbivorous Mammals.

EXPLANATION OF PLATE III.

Fig. 1. Side view of a cast of brain of *Eotherium ægyptiacum.*
2. Upper view of ditto.
3. Under view of ditto.
4. Section of myelon.
5. Upper view of a cast of brain of *Manatus americanus.*
6. Under view of cerebrum.

(*All the figures are of the natural size.*)

DISCUSSION.

Dr. MURIE explained the distinctive characters of the four genera of Sirenian Mammals, *Manatus, Rhytina, Halicore,* and *Halitherium,* and stated that he regarded *Halitherium* as the highest form, seeing that it was a four-limbed type. He remarked that in the young *Manatus* the brain differs in form from that of the adult, which was a fact to be considered with reference to the data on which Prof. Owen's deductions were founded.

Mr. SEELEY said that he had no doubt the brain was Sirenian, and indicative of a new genus. The existing genera differed from it, in his opinion, in having the Sirenian characters more strongly marked rather than in showing a higher cerebral type. In general form the brain reminded him rather of a Carnivore than of a Sirenian; and he thought it indicated affinity with a generalized Carnivorous type more than with the living Sirenians.

Mr. BAUERMAN stated that the section from which this fossil was obtained is about 600 feet high, but the quarries referred to by the author were within about 100 feet of the top, in what had been regarded by Dr. Le Neve Foster and himself as a shallow-water deposit. The lower parts of the Cliff are very like the Chalk with flints, except that they contain Nummulites.

Mr. CHARLESWORTH remarked that the fossil now before the Society was exceedingly interesting, as indicating the extension backwards in time of the Sirenian type. He stated that he did not believe that the English *Halitherium Canhami* was of Miocene age.

Dr. LEITH ADAMS said that the Maltese *Halitherium* was truly Miocene.

Prof. OWEN briefly replied, and concluded by hoping that the objections to any of his conclusions, if reported, would be accompanied by their grounds.

5. A SHORT DESCRIPTION *of the* GEOLOGY *of* PART *of the* EASTERN PROVINCE *of the* COLONY *of the* CAPE *of* GOOD HOPE. By R. PINCHIN, Esq., C.E. (Read December 3, 1873.)

(Communicated by H. W. Bristow, Esq., F.R.S., F.G.S.)

[Abstract*.]

[PLATE IV.]

IN this paper, which was illustrated by maps and sections, the author gave the results of Dr. Rubidge's and his own observations on the geology of the above region. The two principal sections described were from Cape Saint Francis across the Great Winterhoek and Langeberg ranges to the lacustrine Triassic rocks near Jansenville, and from Port Elizabeth to Somerset. The lowest rock in the first section is the quartzite of the Great Winterhoek, which is immediately overlain to the northward by shales and sandstones containing Devonian fossils. Beds with similar fossils occur at the Kromme river, Cape St. Francis, and near Uitenhage. A well-known patch of horizontal Secondary strata stretches west along the Gamtoos river, overlying the Enon conglomerate, as in the case of the Jurassic strata of other parts of Uitenhage. The northern ranges, Langeberg, Klein Winterhoek, and Zuurbergen, are regarded by the author and others as formed of rocks belonging to the Carboniferous series, although closely resembling those of the Great Winterhoek in lithological character, except that among them are bands of the peculiar rock described by Bain as "Claystone-porphyry," by Wyley as a "Trap-conglomerate or hardened Trap-ash," by Jones as a "Trap-breccia," by Atherstone as an "intrusive Trap," and by Sutherland as a "Boulder-clay." Rubidge regarded it as a metamorphic rock; and this view is adopted by the author, who describes it as underlying and overlying the clay-shales, which always separate it from the quartzite, and as passing imperceptibly into the shales.

He says:—"A glance at the map (Pl. IV. fig. 1) shows that this rock does not form a continuous band, as stated by Bain (Geol. Trans. 2nd ser. vol. vii. p. 185), and more or less acquiesced in by geologists since his time—but that it consists of a number of longitudinal patches or strips, more or less parallel with each other, and more or less parallel with the line of strike of the rocks with which it is in all cases interstratified. These longitudinal strips die out as mere threads in some places, and swell to a mile or two miles in width in others. They die out altogether, and are succeeded by other parallel strips at some little distance; and they appear split up, as it were, into double or triple nearly parallel

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* [NOTE.—The subject of this communication is especially referred to and given in some detail in the 'Quart. Journ. Geol. Soc.' vol. xv. (1858), p. 197; 1865, vol. xxi. p. 439; 1867, vol. xxiii. pp. 142, 172; and the 'Geologist,' 1862, vol. v. pp. 47, 56, and pp. 366–372; and especially in the 'Eastern Province Magazine,' vol. i. p. 187, with Section.—EDIT. Q. J. G. S.]

strips, ultimately either dying out or uniting together again, as the case may be. Their interstratification is shown by, and will be best understood upon reference to, the Section, fig. 2.

"In no case is this metamorphic rock contiguous to the quartzite, which is itself more or less metamorphosed, but is invariably separated from it by the clay-shales. It appears underlying and overlying the clay-shales* in synclinal troughs, in anticlinal axes, in every imaginable position, in and within the clay-shale series; but it never touches the quartzite.

"A careful consideration of all of these facts forced the conviction upon my mind that this rock must belong to the clay-shale series, with which it is interstratified, and that it was in all probability metamorphosed since its upheaval and consequent dip. I am the more inclined to this belief, since it is difficult to decide where the one rock ends and the other begins, so imperceptibly do they pass into each other. On the plans and sections (Pl. IV.) I have drawn a hard line of demarcation between these rocks, for the sake of distinctness; but no such abrupt line of division occurs in nature."

Mr. Pinchin expressed his belief that even "the fragments and pebbles of quartz, quartzite, and binary granite" in the great metamorphic band may have been originally such nodules as are now found in the clay-shales, and that the substance of the latter has been converted into the dolerite-like matrix of the former.

The mottled beds of "Ecca rock" are referred by the author to the Carboniferous series. The author also referred to the Post-tertiary and recent rocks containing remains of Mollusca identical with species now living in the adjacent seas, lying unconformably upon the Devonian, and conformably upon the Secondary rocks, at various places near the coast.

EXPLANATION OF PLATE IV.

Fig. 1. Geological Map of the Klein Winterhoek and adjacent country, Division of Uitenhage, Cape of Good Hope.
2. Section along the line A B, in fig. 1.
3. Plan of the country between Port Elizabeth and Somerset, with Bailey's triangulation.
4. Section from Port Elizabeth to Somerset.

Discussion.

Prof. Phillips was struck by the manner in which our system and nomenclature was applicable to a country so remote as the Cape. He was inclined to question the metamorphism of the nodules and concretions in the clay-shales into granites, and commented on the supposed interstratification of metamorphic rocks among unaltered shales. The correlation of the rocks at the Cape with the Devonian and Carboniferous rocks of Europe he thought

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[* See 'Geologist,' vol. v. 1862, p. 54, figs. 4, 5, 6.—Edit.]

most interesting, especially taking into account the distance between the two localities.

Prof. Tennant made some remarks on the gratitude due to the first geological observers in South Africa, who had, by the discovery of the Diamond-fields, so materially added to the wealth of the colony. During the last month he had seen no less than £100,000 worth of diamonds brought over by three persons. At present some twenty thousand persons were employed in the fields ; and the diamonds were equal to any in the world. The trap-rocks in South Africa were as various in their character as those in this country ; and this variety might well lead to speculation as to their origin.

Fig: 1.

GEOLOGICAL MAP

OF THE

KLEIN WINTERHOEK

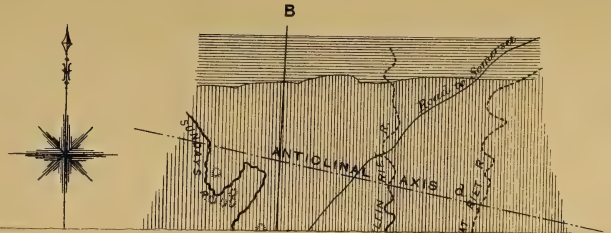
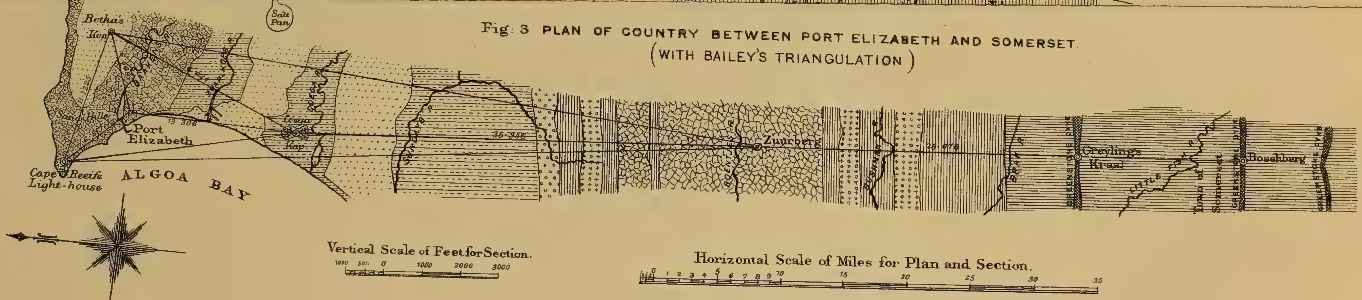


Fig: 3 PLAN OF COUNTRY BETWEEN PORT ELIZABETH AND SOMERSET.
(WITH BAILEY'S TRIANGULATION)



Vertical Scale of Feet for Section.

Horizontal Scale of Miles for Plan and Section.

Fig: 4. SECTION FROM PORT ELIZABETH TO SOMERSET.

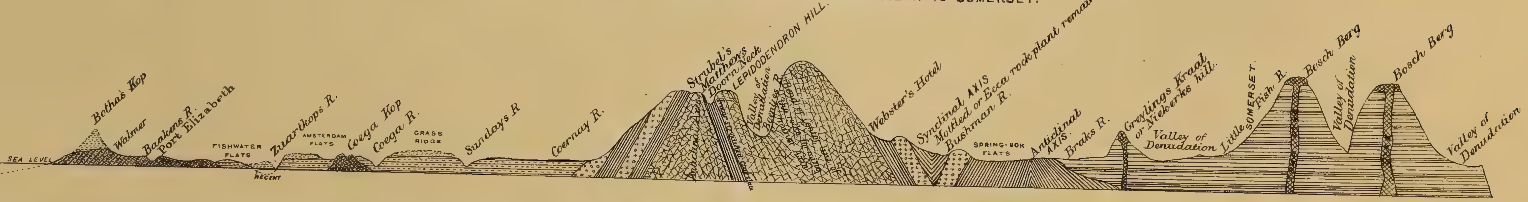


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Fig: 1.

GEOLOGICAL MAP
OF THE
KLEIN WINTERHOEK
and adjacent Country
CAPE OF GOOD HOPE.

Fig 2 SECTION ON LINE A-B.

Scale of Miles

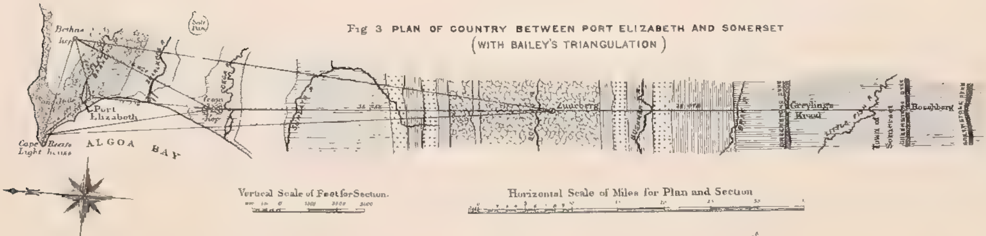
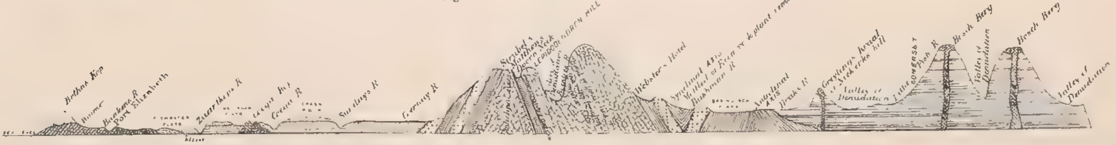


Fig 3 PLAN OF COUNTRY BETWEEN PORT ELIZABETH AND SOMERSET
(WITH BAILEY'S TRIANGULATION)

Vertical Scale of Feet for Section.

Horizontal Scale of Miles for Plan and Section

Fig 4. SECTION FROM PORT ELIZABETH TO SOMERSET.



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6. NOTE *upon a* RECENT DISCOVERY *of* TIN-ORE *in* TASMANIA. By CHARLES GOULD, Esq., B.A., F.G.S. (Read June 24, 1874.)

As a sequel to discoveries of tin-ore in abundance made during the last two years in Queensland and New South Wales, there has been one of some importance recently in Tasmania, which has this special interest, that the ore has been found *in large masses in situ,* and that the containing rock is lithologically distinct from the ordinary ternary granite which forms the whole of the stanniferous country of Queensland, and, so far as my information extends, of New South Wales.

The tin-stone also has an individuality of character not shared by that in the adjacent colonies, occurring in several distinct varieties of form within the distance of a few chains.

I forward a small series of samples for the inspection of the Members of the Society, among which I would specially invite attention to a fragment from a large mass (itself 80 lbs. in weight) which has an appearance on fracture sufficiently approaching to that of a hæmatite to deceive a casual observer.

This discovery of tin-ore has been made at Mount Bischoff, in the N.W. portion of Tasmania. Active operations were only commencing when I visited the spot; and in the absence of mining experience on the part of those engaged, coupled with the numerous obstacles to the progress of pioneers, presented by a rough and exceptionally difficult country, some time may be expected to elapse before its full importance is developed.

Mount Bischoff is distant by the present route fifty-four miles from the place of shipment; and while its vicinity generally is covered with thick forests of myrtle (*Fagus Cunninghamii*), the summit itself (where the tin occurs) is so densely shrouded by an almost impenetrable scrub of *Anodopetalum biglandulosum* ("horizontal scrub" of the colonists) that any estimate of the exposed area of stanniferous rock is impossible at present. It does not appear to exceed a few hundred acres.

Mount Bischoff is a conical eminence, rising to about 2500 feet above the level of the sea, perched on the western edge of the great basaltic plateau of the Surrey Hills, the average elevation of the latter being probably a little over 2000 feet.

It consists of a small protrusion of a porphyritic rock having a felsitic base, with granules and crystals of quartz and felspar; it weathers white, and is honeycombed or vesicular on the surface, most probably from the decomposition and removal of pyrites, which is freely disseminated throughout in places.

The western and southern flanks expose uplifted contorted schists, and metamorphosed formations, among which I noted traces of conglomerates belonging to the lowest of the sedimentary deposits in Western Tasmania.

The basalt on the east in places extends right up to, and rests directly on, the porphyry.

Large quantities of what, in the absence of a better term, may be called stream-tin have been already obtained; and the amount will be much increased when an effective water-supply has been provided and the primitive mode of washing, at present employed, abandoned.

This alluvial tin has not been subjected to the action of the running of the water of brooks, but is procured from the shallow surface-drifts resting on the flanks of the mountain, and is derived directly from the disintegration of veins and strings of ore disseminated through the porphyritic rock.

This latter contains oxide of tin, in small veins in irregular bunches, upon joint faces, and, as I also anticipate, will prove to be the case in large deposits in true lodes.

Gossany outcrops of lodes or irregular deposits occur of great extent in places; and in these are met with ferruginous agglomerations of minute particles of tin-stone, forming projecting boulder surface-masses of great size. Nuggets (as they are locally termed) or shoad-stones of rich tin-ore are freely discovered, varying up to four or five hundredweight in size.

Surface-indications of large lodes are also seen, in which a clayey material is traversed by strings of galena, of iron pyrites, and by large quantities of carbonate of iron; no attempt has yet been made to ascertain their nature or develop them.

Unquestionable lodes in the adjacent slaty rocks contain antimony and zinc blende. The average direction of those yet discovered is from 10° to 20° to west of north, and east of south.

I regret that the brevity of my stay at Mount Bischoff, and the undetermined character of the main deposits of ore, prevent me from at present giving fuller details of what will, I think, prove to a very important discovery.

7. *An* ACCOUNT *of a* WELL-SECTION *in the* CHALK *at the north-end of* DRIFFIELD, EAST YORKSHIRE (*supplementing the writer's previous paper**). By R. MORTIMER, Esq. (Read March 25, 1874.)

(Communicated by W. Whitaker, Esq., B.A., F.G.S.)

[Abridged.]

THIS well was dug in the spring of 1873. The site is on ground at at an elevation of 120 feet above the level of the sea, and slopes gently towards the south. The first 7½ feet of the section was through the feather-edge of a bed of clay of late glacial age, in which, at a depth of 6 feet, lay a large and irregularly formed boulder of trap-rock, with angles but slightly worn; there were portions of several other rocks. Under this clay is chalk in a very rubbly and broken-up state, to a depth of from 3 to 4 feet, after which it gradually loses the broken-up appearance, and assumes the horizontal laminated form. The chinks and fissures in the upper portion of the chalk were stained to a depth of 8½ feet with argillaceous matter from the percolation of rain-water through the overlying clay; but beneath this depth there was no colouring-matter visible from above.

The portion of the section which passed through chalk was 47 feet in depth. A careful examination showed that horizontal laminæ existed from top to bottom, and varied in thickness from $\frac{1}{16}$ of an inch to 16 inches. From a depth of 20 feet to the bottom, the sides of the well exposed many nearly vertical partings, or faces, in the chalk, where horizontal striæ were beautifully shown, covering several square feet together. One large buttress-formed piece exhibited two sides of a square elaborately filled with horizontal striæ. At a point about two thirds of the depth of the well, the face of the chalk showed the same kind of markings, but in this case making an angle of about 45 degrees with the horizon. These striated fissure-like partings in the chalk, many of which appear to have never been firmly united with the mass, ran in all directions. In one place several feet of striæ ran from north to south, while above and below these facets pointed in every direction. No appearance of flint was observed.

Intimately connected with, and spread between the hard chalk laminæ were numerous thin horizontal layers of a softer and muddy-coloured substance (fuller's earth), of the consistency of compact clay. This material, varying in thickness from ¾ of an inch down to a mere film (though in some of the chalk-pits in the neighbourhood it is occasionally from 2 to 3 inches thick), is here found between all the horizontal layers of the chalk. At the depth of 31 to 38 feet there are three beds about 3 feet apart, and measuring from ½ an inch to ¾ of an inch in thickness. This fuller's earth, when first taken from the rock, is of a tenacious nature, but in

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* Quart. Journ. Geol. Soc. vol. xxix. (1873) p. 417.

drying becomes more friable, and frequently breaks up into scaly pieces, which warp and curve. It seems to be composed of comminuted chalk and shells mixed with decayed animal and vegetable remains; in short it consists, for the most part, of the wreck of oceanic life; and a comparison of the two chemical analyses given below, which were made by a well-known analytical chemist (Mr. Thomas Hodgson, of Under Cliff, Bradford), strongly supports this belief:—

Analysis of sample of chalk from the well-section at Driffield:—

Moisture	5·20
Carbonate of lime	93·30
Carbonate of magnesia	·15
Oxide of iron and alumina	·20
Silica	1·15
	100·00

Analysis of sample of fuller's earth from the well-section at Driffield:—

Moisture	12·15
Organic matter and water combined	1·67
Carbonate of lime	33·40
Carbonate of magnesia	·50
Oxide of iron	7·05
Alumina	10·23
Alkaline salts	·20
Silica	34·80
	100·00

The author adduces the facts above alluded to in support of his hypothesis that the solid chalk is built up by organisms of a zoophytic nature, and regards the clayey layers as caused by temporary disturbances of the water by which the ordinary quiet "secretion" of the chalk was interrupted.

Discussion.

Prof. Hughes thought that the origin of the particular structure referred to by Mr. Mortimer was a question for mineralogists and chemists, though somewhat similar forms might be produced mechanically. He pointed out that its occasional occurrence along fissures not in the line of bedding was quite conclusive against its being in any way referable to the period of original deposition. As to the more clayey bands, he considered the Chalk, though often composed in a great measure of comminuted organisms, to be all sedimentary, and had therefore no difficulty in explaining how more clayey matter might accumulate over various areas at different times.

Mr. Wiltshire mentioned that argillaceous bands extending over wide areas are to be observed in the Chalk.

Mr. Whitaker stated that clay bands occur near Beachy Head. He considered that the argillaceous bands are not seen in hard chalk. The analyses given by the author were of much value.

Mr. Charlesworth remarked that the Yorkshire Chalk presents exceptional characters. The sponges found fossilized in it are silicified throughout, but the silica is confined to the sponges, and does not invest them.

Mr. Koch stated that near Nice the Dolomitic Limestone sometimes exhibits a structure similar to that described in the paper, and that when this structure occurs minute crystals can be detected in the mass.

8. *On* Slickensides *or* Rock-striations, *particularly those of the* Chalk. By Dr. Ogier Ward. (Read March 25, 1874.)

(Communicated by Prof. Morris, F.G.S.)

This subject has been so recently brought under the notice of the Society that I need not describe the appearances; but as there seems to be a most extraordinary divergence of opinion as to their cause I have used the general term of "slickensides," meaning "slipping of surfaces."

In the cretaceous strata of the neighbourhood of Eastbourne these striations may almost be measured by acres, almost every block in the Holywell quarries having its sides either striated or polished; and in the angles of the blocks, where the chalk has been crushed, the striations assume various directions and curvatures, according, I believe, to the direction of the crushing force. Each surface of the large blocks has one uniform line of striation, though the other sides may be perpendicularly, horizontally, or diagonally striated, as if each block had been moved in various directions. The surfaces of the blocks are more or less embossed; but the striæ enter into all the irregularities, and it often happens that a detached piece of rock lies crushed into a hollow, like a dab of mortar, yet both its external surface and that of the cavity in which it lies are striated by lines in continuity with those of the rest of the surface. Mr. Fordham doubts the existence of horizontal striation; but since his paper was read I have had the pleasure of showing him these phenomena, which have shaken his previous opinion, if not convinced him of the correctness of the slickensides theory. The great difficulty I meet with is to account for the sudden steps or breaks, which give to the surface the fibrous appearance of petrified wood, described by Mantell, but which he attributed to its true cause. In this way I account for the fibrous form, by the disturbance having acted only at *short* distances; for it is not on the large surfaces of the blocks that it is found, but in the angles between the blocks, where pieces detached from the adjoining blocks have been crushed into the angles to fill up the vacancy when the blocks settled down again into their former places.

My attention was first called to this subject by finding an Echinoderm imbedded in a fissure, with its exposed surface striated; and soon afterwards I found others crushed, with taluses formed behind their tubercles in the line of pressure. With such evidences of movement in the chalk I began to examine the fissure-, and rock-surfaces; and I found not only striations and polished surfaces, but calcareous spar, true slickensides, filling up fissures in the chalk, marl, and greensand. I have found exactly the same appearances in the chalk of Brighton and Lewes; and having examined various rocks (mountain-limestone, coal, serpentine, iron, red sandstone, slate, and surturbrand) and found similar striations, I think it illogical to assign a different reason for them and those in the chalk, and hence I venture to include *all* striated and polished surfaces under the general term of slickensides. The surfaces of the striated rocks are harder than the chalk within, I presume, from the pressure and condensation; but the fragments in the angles when fresh are very friable, splitting with the greatest ease in the lines of striation, and each face is also striated. Some of the faults in the chalk-marl are filled with compressed fragments, each surface of which is striated; and the contorted strata are similarly marked. In this neighbourhood, at least, I am convinced that striation is always attended with disturbance of the strata; and I venture to say that neither the coralline nor the crystalline theory is supported by the microscope, which has never revealed zoophytes or crystals, except where slickensides have been moulded on the sides of fissures—and that "cone in cone" is a substantial structure, while striations are entirely superficial. The concretionary chalk, of which Mr. Fordham has kindly sent me specimens, is common here, where it is called "hommy mommy" by the workmen. It is much harder than the chalk or chalk-marl, and is therefore rejected for lime-burning. It is not so often striated as the other forms of chalk.

Discussion.

Mr. Whitaker said that some of the specimens on the table sent by Dr. Ward showed slickensides, but that in certain cases the fibrous structure runs through the whole substance.

Mr. W. T. Blanford stated that he had seen a similar structure in an undisturbed white clay resembling pipeclay; so that he thought the appearance could not be produced by motion.

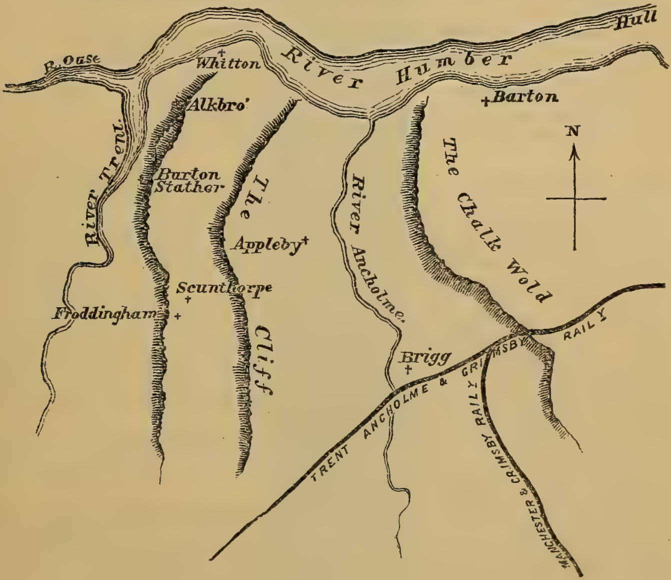
Mr. Evans remarked that the structures brought forward appeared to be of two kinds:—first, slickensides pure and simple; and secondly, fibrous structure,—the latter probably due to chemical action, either by an incipient formation of aragonite, or by the formation of that mineral and its subsequent partial decomposition.

9. *The* Geology *of* North-west Lincolnshire. By the Rev. J. E. Cross, M.A., F.G.S. (Read November 18, 1874.)

[Plate V.]

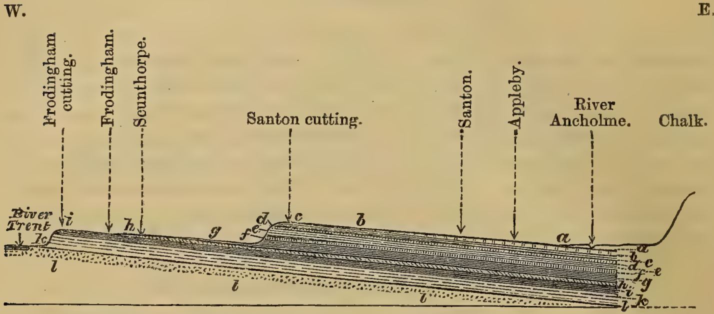
The locality to which I would draw attention this evening is the extreme north-west corner of the county of Lincoln—the district, in short, as the rough map (fig. 1) will show, bounded by three rivers, the well-known Humber and Trent and, eastwards, the little Ancholme—this last a strange name to modern ears, but one which has been honoured by the mention of that old English classic, Isaac Walton. It is a corner of the land unknown to fame; but we are now becoming celebrated commercially by the recent discovery of a most extensive and valuable deposit of iron-ore, respecting which I shall have something to say by and by. But, besides this commercial importance thrust upon us, the district has a special value in the eyes of the geologist as being a middle link in the chain of the Jurassic strata, between their development in the south and their somewhat dissimilar appearance on the Yorkshire coast. The labours of Mr. Judd and Mr. Sharpe, in the southern portion of the county, have brought into clear light the commencement of this variation. But the state of things in this northern corner has not as yet been brought before your notice.

Fig. 1.—*Sketch Map of N.W. Lincolnshire.*



The accompanying section (fig. 2) gives a general idea of the district. Three escarpments are represented, and two long sloping plains between them. The westernmost scarp is capped with Lower Lias (*Bucklandi*-zone), the middle one with Lincolnshire Limestone; and the easternmost is the Chalk Wold. Both these latter elevations are characteristic and enduring features in the county. The limestone-ridge is called the "Cliff," and runs pretty nearly due south from the Humber to Lincoln, and further. The wold trends S.E. towards Boston and "The Wash." The westernmost elevation of the three is not so continuous. What I desire to do now is to give a slight sketch of the Liassic and Oolitic strata here exhibited, from west to east, from the lower rocks to the higher.

Fig. 2.—*Section from the Chalk Wolds of N.W. Lincolnshire to the River Trent.*



a. Cornbrash and Great-Oolite clay.
b. Lincolnshire Limestone.
c. Upper Lias clay.
d. *Rhynchonella*-bed.
e. *Capricornus*-clay—Middle Lias.
f. *Pecten*-bed.
g. Lower Lias clay.
h. Scunthorpe Ironstone.
i. *Bucklandi*-beds.
k. Infra-Lias.
l. Keuper.

The bed of the river Trent is in the Keuper Marls (fig. 2, *l*). When a railway-bridge was built here a few years back the sinkings for the piers were all through this formation.

It would be natural to suppose, then, that the Rhætic beds would make their appearance on the eastern shore, especially as they have been found well developed elsewhere in the county; but I have as yet no sufficient proof of their existence. Nor do I find any trace of the famous bone-bed, nor, again, any single specimen of *Avicula contorta*, for which I have searched very diligently. Nor have I seen any one specimen of the true *Ammonites planorbis*. As far as my researches go, the first strata next above the Keuper are those which contain *Ammonites angulatus* and *A. Johnstoni*; and if this is so, a considerable gap in the series is exhibited. As regards these two Ammonites, both appear together in the lowest beds (figs. 2 & 3, *k*); but *A. angulatus* seems to reach far above the extreme limit of the other, throughout a zone of, say, 150 feet or more.

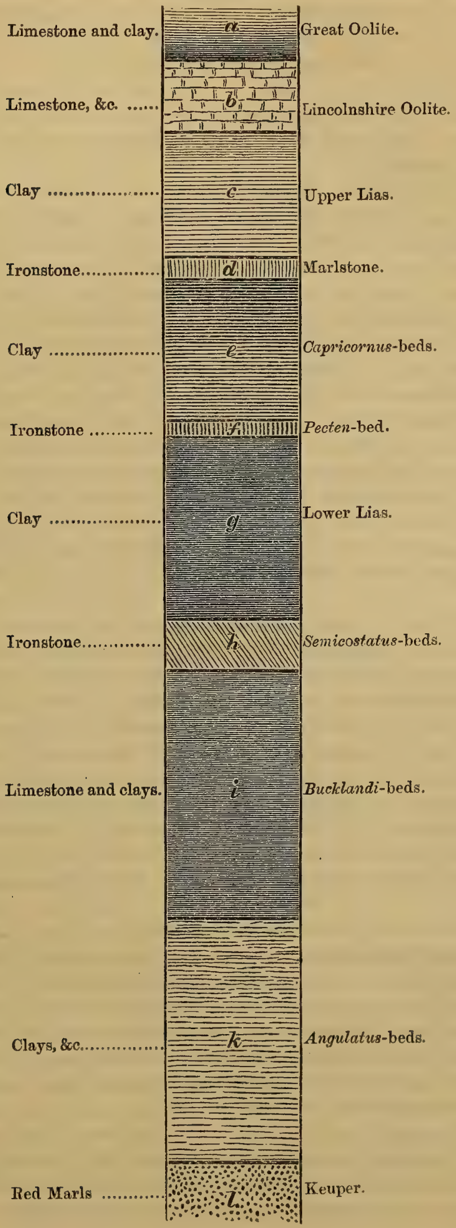


Fig. 3.—*Vertical Diagram Section of the Jurassic beds of N.W. Lincolnshire.*

Along with these two Ammonites, apparently from the lowest beds upwards, there are various *Ostreæ* and *Gryphææ* in greater numbers than one might have expected:—one kind approaching to the *Gryphæa incurva* of the higher beds, yet keeping, I think, a distinctive form; another, large and wide, which I have been accustomed to call *G. grandis*, but I dare say it is not really new. There is also the *Ostrea irregularis* or *liassica* and the *O. rugata* of Quenstedt. I give a list of the fossils found in this and the other beds of the district.

Above this the true *Gryphæa-incurva* zone is well developed and well exhibited in a deep railway-cutting (that of Frodingham) which strikes the hill just about the top of the *A.-angulatus* zone. It consists of a series of blue clays and rocks in layers (figs. 2 & 3, *i*), and contains Ammonites of the *Bucklandi* type. The figure of *A. Bucklandi*, engraved in Dr. Wright's 'Ammonites of the Lias,' is there stated to have been from a specimen found in a Lias railway-cutting near Brigg. This is doubtless the spot I am treating of. *Ammonites semicostatus* is pretty common, *Gryphæa incurva* in thousands, and most of the usual fossils of the zone, *Lima gigantea*, *Pentacrinus* of two kinds; *Spiriferina Walcotti* is rare.

It is next above these beds that we come upon the peculiar and interesting formation of our Lias, viz. a thick and rich deposit of iron-ore (figs. 2 & 3, *h*). Fifteen years ago this formation was wholly unknown; and it is entirely due to the persevering investigations of the present proprietor, Mr. R. Winn, M.P., that it has been brought to light.

And first, as to the geological place of this ore. It is undoubtedly Lower Lias, and low down in the same. The Ammonites it contains are still chiefly the keeled *Arietes*, or those keeled Ammonites which are next above them—*A. Bucklandi* or some cognate species, *A. semicostatus* (commonest of all, but very badly preserved), *A. Conybeari*, *A. Brookii* of Quenstedt's Jura (which seems not to be Sowerby's *A. stellaris*), the species called *A. aureus* by Dumortier, one solitary specimen which is undoubtedly the *A. Boucaultianus* of D'Orbigny, *A. Boblayi* of Buckman, and two large species which may, perhaps, be identified with figures in Quenstedt's Jura, under the names of *A. Scipionanus* and *compressaries*.

Univalves are very rare (as indeed they are throughout the whole district); but *Pleurotomaria anglica* has been found. *Lima gigantea* is large and common; there is also a dwarf *gigantea*, if I may so term it, and *Lima Hermanni* or *antiquata*; *Gryphæa*, usually a little wider than the ordinary *incurva*, but passing insensibly into it; *Nautilus striatus*, *Belemnites acutus*. Besides these ordinary shells there are a few which are somewhat out of the common line:—a small *Myoconcha*, apparently the *M. Oxynoti* of Quenstedt; the *Gervillia betacalcis* of the same author; and, I think, his *Cucullæa ovum*. A pretty little *Astarte* is very common, which Mr. Etheridge identifies with his *A. dentilabrum*. There is also, in considerable plenty, a small *Hippopodium*, greatly resembling one which Mr. C. Moore has figured in his 'Middle Lias of the South-west of England.' If my species is new, I propose to assign to it the designation "*ferri.*"

Another new shell (new, at least, in this country, and very common in this bed) is a small *Tancredia*. It does not even seem exactly to resemble any of the foreign Liassic species; and I would give it the name of "*ferrea.*"

But the prevailing fossils of the bed are the *Cardiniæ*. These occur in countless multitudes, beautifully preserved, many of them transparent, being filled with calcite, and of five or six different species, among which the *C.* (*Thalassites*) *gigantea* of Quenstedt is magnificently conspicuous; the others are allied to *C. crassissima* (Sowerby), *copides* (Ryckh.), *regularis* (Terquem), *elliptica* (Agass.) or *Morrisi* (Terquem). I do not venture to name them till they have undergone a further investigation.

I think it is manifest, from this description of its fauna, that this remarkable ironstone lies low down in the Lower Lias—say, on the border-line between Quenstedt's α and β; and I insist upon this, and would call special attention to it, because it has been hastily assumed, by those who are commercially engaged with it, that it is of similar age with the marlstone-iron series of Cleveland. This is quite impossible; and if I am right, then, I take it, we have here a development almost unique in this country; for I doubt whether any iron-ore so low down in the series is found in workable quantity anywhere else (unless, indeed, it be a continuation of the same bed that is worked at Caythorpe, near Grantham, a more recent discovery, which has followed upon this one here).

As regards its quantity and quality, it is some 27 feet in thickness, and crops out upon the surface, covering the whole wide plain of the village of Scunthorpe, so that no mining is at present required. It commences below with a hard limestone band, in which, and in somewhat similar bands above, most of the fossils lie; these are intercalated with softer bands of a darker brown colour and rubbly texture, intermingled with a brown dust. As it differs from the well-known ore of Cleveland in its palæontological contents, so it also differs from it mineralogically. The stone of Cleveland is rich in silica, and requires a flux of limestone in the furnace. This ingredient (silica) is almost wanting in the Scunthorpe stone; and lime is superabundant. When first this ore was worked, this excess of lime was not understood, and many hundred tons of Oolite-limestone were brought, at considerable expense, from neighbouring parishes, only to make bad worse. Most happily, with the discovery of the real want came the discovery of the means of supplying it; a good iron-ore highly charged with silica has turned up close to the city of Lincoln; and this is now mixed with the mass in the proportion of about $\frac{1}{8}$ of the whole.

The yield of metal is about 1 ton to $3\frac{1}{4}$ of ore; say, 27 or 28 per cent.

This important bed has now brought us to the foot of the second or middle escarpment of the section fig. 2. I proceed to ascend this second hill and to pass on eastwards.

A thick bed of blue marl (figs. 2 & 3, *g*) succeeds, 90 feet in depth, its lower portion the home, probably, of *Ammonites oxynotus*; but no opening has been made of any importance in the lower portion of this marl, and its contents are unknown. Since writing, I have found in it a little *A. Birchii*, Sow. Its upper portion is crossed by bands of chert nodules, and has yielded *Ammonites raricostatus, Taylori*, and, perhaps, the *Polymorphus mixtus* of Quenstedt. A little higher, again, in the same, I find *A. Loscombei, Oxynotus numismalis* (Quenst.), and *Natrix rotundus* (Quenst.), the last imbedded in the nodules, the others chiefly in the clay; with these are a large *Pinna*, *Pholadomya ambigua* of a huge size, *Gryphœa Maccullochi*, and *Belemnites paxillosus*. A narrow ironstone-bed (figs. 2 & 3, *f*) follows, consisting of a rocky band 4 feet thick, the slabs crowded with Pectens of a good size. They resemble the shell which Phillips figures, in his 'Geology of Yorkshire,' under the name of "*sublævis*, Young and Bird;" (on turning to "Young and Bird," however, I think that for *sublævis* we should read "*subrufus*"). From this profusion of Pectens we have named the bed the *Pecten*-ironstone. The Ammonites it contains are *A. armatus* and *Henleyi*, which sufficiently define its place in the series. I must mention one other of its fossils, a large *Tancredia*, which seems wholly new, and to which I would give the name "*liassica*."

We now reach the border between the Lower and Middle Lias, the latter represented by some 66 feet of blue clay (figs. 2 & 3, *e*), containing, throughout, in the centres of cement nodules, the *A. maculatus* (*Capricornus* of Schlotheim).

A railway-cutting, called Santon cutting, drives right into this clay; but few fossils are to be gathered. It is capped by a narrow bed of 18 inches (not marked in the sections), containing a confused mass of broken Belemnites and other shells, together with many coprolites and much pyrites, the whole of a bright green colour.

The true Middle Lias (the zone of *A. margaritatus* and *spinatus*, which lies next above in the normal series, is reduced with us to very slender proportions. The *margaritatus*-beds seem to be wholly missing; and we find only 8 or 9 feet in all between the occurrence of *A. maculatus* and *A. communis*. This 8 feet is represented in the sections by the band marked *d*. We call it the *Rhynchonella*-bed, from the frequent occurrence in it of *R. tetrahedra*; it consists, as far as my knowledge goes, of a hard light-grey limestone, weathering to brown, and seems to contain *Ammonites spinatus* (Brug.) towards the lower part, and *A. communis* and *serpentinus* in the upper.

Above this, again, the Upper Lias is represented by a bed (marked *c* in the sections) about 60 feet in thickness, but very little explored. It seems to consist chiefly of a blue shale, with casts of Ammonites of the *falcifer* type; and I think it shows no trace of Upper-Lias sands.

And now we reach the summit of the middle escarpment in my section, and leave the Lias for the Oolites.

The great formation now called "Lincolnshire Limestone" (figs.

2 & 3, *b*) is the main representative of the Inferior Oolite in this district, and at first sight might seem to be its only representative; but I find certain beds at the bottom of this formation differing but little in outward appearance from the rest, yet containing a somewhat different fauna. I have called these, by way of distinction, the Santon Oolites. They show a soft, dark-coloured, ferruginous bed, and an oolitic limestone bed above it.

The softer bed yields a Belemnite (a rarity in our Oolites), *Ceromya bajocciana*, *Pinna cuneata*, *Gervillia acuta*, *Ostrea mima*, *Hinnites abjectus*, *Pholadomya fidicula*, two *Nerinææ*, two beautiful little *Trochi*, and one solitary specimen of an Ammonite, thin as *A. oxynotus* and well keeled, which has been pronounced to be of the family of *A. Truellei*. The stony bed above yields most of these, and in addition to them, *Astarte elegans*, *pumila*, *squamula*, and *minima*, *Opis cordiformis*, *Corbicella complanata*, *Macrodon hirsonensis*, two *Cyprinæ*, a large and fine *Cardium* something like *cognatum*, and two *Trigoniæ* in beautiful preservation (*T. hemisphærica* and *Phillipsii*.)

Whatever these beds may represent, I almost fancy that they are dying out here, as I cannot persuade myself that they are altogether continuous, but seem to occur in patches. A little further south, I fancy, they become more permanent.

Above this lies the Inferior-Oolite stone now often termed Lincolnshire Limestone, which, with its partings of clay, has an average thickness of 12 yards. One single specimen of an Ammonite, so far as I know, is the only representative of its kind, nay, of all the Cephalopods, in this formation. It is of very considerable size, and belongs to the *Humphriesianus*-group. It is not, I am sorry to say, in my possession. The rest of the fauna corresponds very closely with the lists usually given from these beds in other districts. I may, however, single out for mention the little *Rhynchonella Crossii*, to which Mr. Walker has been pleased to append my name, it having been first brought into notice by me. It is a beautiful little shell, seldom exceeding the size of a pea, and filled with pure calcite; the spines are very thick and strong; of what length originally, cannot be told; for, from the hard nature of the matrix, it is impossible to extract them whole; but they leave a very deep and notable impression behind them. Also I may notice a dwarf variety of *Trigonia hemisphærica*, measuring about an inch each way, which is only about half the size this species attains in the beds (just described) below. I am not aware whether this shell is similarly dwarfed in the corresponding beds elsewhere. I should notice also the extreme rarity of *Pholadomya fidicula*, *P. Heraultii* being the prevailing species.

Next above the Lincolnshire Limestone there exists a deep clay (figs. 2 & 3, *a*), perhaps 40 feet, of a bright green colour in parts, the representative, doubtless, of some member of the Great Oolite series. I have not had good opportunities of observing it; and its fossils are many of them in very bad condition; but among them are *Ostrea subrugulosa*, *O. Sowerbyi*, *Gervillia crassicosta*, *Modiola ungulata*, *Trigonia flecta*, an Icthyodorulite, and fish-palates.

And, lastly, capping this clay, there is but one formation more; and that is either Forest marble or Cornbrash, probably the latter. It is pretty well determined by its two Ammonites (*A. macrocephalus* and *Herveyi*), by its two *Terebratulæ* (*T. lagenalis* and *obovata*), and by the rest of its fauna generally. One of its *Trigoniæ* (*Moretoni*) appears in great beauty, and has been figured in Dr. Lycett's work; and a second species, pronounced by him to be new, will, I believe, appear in his forthcoming publications. There is one other new bivalve to which I would direct attention—a little costated *Opis*. There are two figures in Phillips's 'Geology of Yorkshire,' both termed "*Cardita similis*," one from the Coralline Oolite, the other from the Dogger, which somewhat resemble it; but it is hardly possible that either of them can represent the shell to which I refer.

Cornbrash occupies the surface of the ground eastwards until the level alluvium of the plain of the Ancholme draws a final veil over all researches. Further eastward I do not propose to pass: indeed, in a direct easterly line we find nothing Oolitic; east of the alluvial plain of the Ancholme, chalk-rubble covers all, till the high Chalk wold raises itself above it. A little further south the Kimmeridge Clay shows itself between, but not so just here. And with the mention of this my task is done. I have exhibited (in a very imperfect and unsatisfactory manner, I fear) my panorama of the North Lincolnshire Lias and Oolites; and if I have happily succeeded in interesting my hearers at all it will be, I am sure, only because of the novelty of the *Ultima Thule* I have treated of. I hope more competent observers may think it worth while to come upon the scene and to check the crude views that have been advanced by me here. If on any point these views should be found to be erroneous, I can only say no one will rejoice more than myself that the actual truth should be elicited.

LOWEST LIAS.

Valley of the Trent.

Ammonites Johnstoni, *Sow.*
—— angulatus, *Schloth.* (var. catenatus, *D'Orbigny,* var. moreanus, *D'Orbigny.*
Nautilus striatus, *Sow.*
Pleurotomaria basilica? (*Chap.*)
——, sp.
—— psilonoti, *Quenst.*
Turritella Deshayesia?, *Terq.*
Cardinia crassissima, *Ag.*
—— Listeri, *Sow.*
——, oval sp.
Astarte obliqua, *Desh.*
Pleuromya Dunkeri, *Röm.*
Myacites liasinus, *Ziet.*
Homomya, sp.
Pholadomya prima, *Quenst.*
Cardita Heberti?, *Terq.*
Modiola nitidula, *Dunk.*
Modiola, sp.
Arca, sp.
Unicardium cardioides, *Phill.*
Avicula decussata.
Lima gigantea, *Sow.* (var.)
—— Hermanni, *Voltz.*
—— hettangiensis, *Terq.*
——, small ribbed sp.
Pecten valloniensis? (doubtful).
——, small smooth sp.
Gryphæa, n. sp.
—— incurva, *Sow.* (var.).
Ostrea irregularis, *Goldf.*
—— rugata, *Quenst.*
—— liassica, *Strickl.*
Carpenteria (Terquemia).
Pentacrinus.
Spines of Cidaris.
Montlivaltia Haimei, *Chap.*

Gryphæa-incurva Zone.

Frodingham Railway-cutting.

Ammonites Bucklandi, *Sow.*
—— semicostatus, *Y. & B.*
—— Conybeari, *Sow.*
Nautilus striatus, *Sow.*
Belemnites acutus, *Mill.*
Pleurotomaria anglica, *Sow.*
Trochus, sp.
Unicardium cardioides, *Sow.*
Cardinia Listeri, *Sow.*
—— concinna, *Sow.*
Pholadomya ambigua, *Sow.*
Modiola, sp.
Avicula inæquivalvis, *Sow.*
Lima gigantea, *Sow.*
Lima Hermanni, *Voltz.*
—— dupla, *Quenst.*
——, small single-ribbed sp.
Pecten textorius, *Schl.*
——, small ribbed sp.
——, small smooth sp.
Pinna.
Gryphæa incurva, *Sow.*
Ostrea arietis, *Quenst.*
Rhynchonella.
Spiriferina Walcotti, *Sow.*
Pentacrinus, 2 sp.
Montlivaltia Haimei, *Chap.*

Lower Lias.

Scunthorpe Ironstone.

Ammonites Bucklandi ?, *Sow.*
—— Conybeari, *Sow.*
—— semicostatus, *Y. & B.*
—— Brookii, *Quenst.* (non *Sow.*).
—— aureus, *Dumortier.*
—— gmundensis, *Dumortier.*
—— Boucaultianus, *D' Orb.* 1 sp.
—— Scipionanus ?, *Quenst.*
—— compressaries ?, *Quenst.*
Nautilus striatus, *Sow.*
Belemnites acutus, *Mill.*
Pleurotomaria anglica, *Sow.*
Tancredia ferrea, n. sp.
Cardinia gigantea, *Quenst.*
—— copides ?, *Ryckh.*
—— crassissima ?.
—— Morrisi ?, *Terq.*
——, n. sp.
Astarte dentilabrum, *Ether.*
Cucullæa ovum, *Quenst.*
Pholadomya ambigua, *Sow.*
Myoconcha Oxynoti, *Quenst.*
Modiola Oxynoti, *Quenst.*
—— Morrisii, *Oppel.*
Hippopodium ferri, n. sp.
Gervillia betacalcis, *Quenst.*
Lima gigantea, *Sow.*
—— ——, small variety.
—— Hermanni, *Voltz.*
—— hettangiensis, *Terq.*
—— dupla, *Quenst.*
Pecten æqualis, *Quenst.*
—— demissus, large, smooth (*demissaries* nobis).
—— texturatus, *Goldf.*
Gryphæa incurva, *Sow.*
Carpenteria, sp. (Terquemia).
Spiriferina Walcotti, *Sow.*

Clay below Pecten-*bed.*

Ammonites raricostatus, *Ziet.*
—— Taylori, *Sow.*
—— polymorphus mixtus ?, *Quenst.*
—— lineatus, *Schloth.* ?
—— Loscombei, *Sow.*
—— oxynotus numismalis, *Quenst.*
—— natrix rotundus, *Quenst.*
—— Henleyi, *Sow.*
Belemnites paxillosus, *Schl.*
—— clavatus, *Schl.*
Myacites unionides, *Röm.*
Pholadomya ambigua (very large).
Sanguinolaria striata, *Buckm.*
Pinna folium, *Y. & B.*
Plicatula spinosa, *Sow.* (small).
Gryphæa Maccullochi, *Sow.*
Spiriferina, sp., very rare.
Terebratula numismalis.
—— numismalis ovalis, *Quenst.*
Pentacrinus (very rare).

Pecten-*bed.*

Ammonites armatus, *Sow.*
—— Henleyi, *Sow.*
Belemnites elongatus, *Mill.*
Unicardium cardioides.
Cardium multicostatum, *Phill.*
Cypricardia, sp.
Cyprina, sp.
Cucullæa.
Cardinia hybrida, *Sow.*
Nucula.
Myacites unionides, *Röm.*
Goniomya (rare).
Tancredia liassica, n. sp.
Pecten, sp. (like sublævis, *Phill.*).

Pecten corneus, *Goldf.*
Lima Hermanni, *Voltz.*
—— antiquata, *Sow.*

Terebratula punctata.
Rhynchonella variabilis, *Schl.*
Spiriferina (very rare).

MIDDLE LIAS.

Santon Railway-cutting.

Ammonites maculatus, *Y. & B.* = capricornus, *Schl.*
Belemnites paxillosus, *Schl.*
Natica.
Cardium lobatum ?, *Quenst.*
Nucula complanata.
—— inflata, *Quenst.*
Myacites, 2 sp.

Goniomya (rare).
Plicatula spinosa (small).
Ostrea læviuscula, *Sow.*
Pinna.
Lima acuticosta, *Quenst.*
Avicula inæquivalvis, *Sow.*
Gervillia lævis ?, *Buckm.*
Rhynchonella variabilis, *Schl.*

Rhynchonella-bed, east end of above cutting.

Ammonites spinatus, *Brug.*
—— cornucopia, *Y. & B.*
—— communis, *Sow.*
—— serpentinus.
Belemnites paxillosus (large).
Myacites unionides, *Röm.*

Goniomya.
Avicula cygnipes, *Y. & B.*
Terebratula subpunctata, *Dav.*
Rhynchonella tetraedra.
Spiriferina (very rare).

SANTON OOLITE.

Marly bed below.

Ammonites, one specimen allied to A. Truellei.
Belemnites.
Modiola ungulata, *Y. & B.*
Pholadomya fidicula, *Sow.*
Ceromya bajocciana, *D'Orb.*
—— cornuta, n. sp.

Ostrea mima.
Pecten lens, *Sow.*
Hinnites abjectus, *Phill.*
Gervillia acuta, *Sow.*
Pinna cuneata, *Sow.*
Trichites nodosus, *Lycett.*
Glyphæa.

Limestone above.

Nerinæa, sp. (near to N. Cotteswoldiæ, *Lyc.*).
Turbo, n. sp.
Trochus, n. sp.
Neritopsis, n. sp.
Natica (Euspira).
Cerithium, sp.
Alaria, sp.
Pholadomya fidicula, *Sow.*
—— Heraultii, *Agass.*
Ceromya bajocciana, *D' Orb.*
Modiola cuneata ?.
—— Leckenbyi ?.
Trigonia hemisphærica, *Lyc.*
—— Phillipsii, *Lyc.*
Opis cordiformis.
Corbicella complanata, *Lyc.*
Astarte elegans, *Sow.*
—— pumila.
—— squamula.
—— recondita, *Phill.*
—— minima, *Sow.*
—— divaricata, n. sp.
Cypricardia bathonica, *D' Orb.*
Cyprina trapeziformis, *Römer.*

Corbula.
Cardium, sp. (like cognatum, *Phill.*).
—— striatulum, *Sow.*
Isocardia cordata, *Buckm.*
Nucula Hammeri, *Def.*
—— variabilis.
Cucullæa oblonga, *Sow.*
—— ornata, *Phill.*
—— Rolandi, n. sp.
Myacites.
Gresslya ?.
Ostrea mima.
Pecten aratus, *Waagen.*
—— lens, *Sow.*
Lima rigidula.
——, large sp. (like Hermanni).
Hinnites abjectus, *Phill.*
Gervillia acuta, *Sow.*
Macrodon hirsonensis, *Mor. & Lyc.*
Serpula.
Echinus.
Cidaris.
Pentacrinus (dwarf sp.).
Small corals.

Inferior Oolite.

Lincolnshire Limestone.

Ammonite, one large specimen only known: Humphriesianus type.
Pleurotomaria pallium, *D' Orb.*
—— armata, *Münst.*
——, sp.
——, sp.
Natica adducta, *Phill.*
—— leckhamptonensis, *Lycett.*
——, large sp. (cast).
—— (Euspira) (cast).
Purpurina, sp.
Nerinæa Jonesii, *Buckm.*
Cerithium (cast).
Turbo oppellensis, sinistral sp., *Lyc.*
Eulima (cast).
Patella rugosa, *Sow.*
Dentalium.
Modiola ungulata, *Y. & B.*
—— Lonsdalei, *Lycett.*
—— Leckenbyi ?.
—— aspera, *Sow.*
Pholadomya fidicula, *Sow.* (very rare).
—— Heraultii, *Agass.* (common).
Homomya crassiuscula.
—— gibbosa.
Goniomya V-scripta, *Sow.*
Cardium.
Unicardium.
Cypricardia acutangula, *Phill.*
Astarte rhomboidalis, *Phill.*
Trigonia hemisphærica, var. (dwarf), *Lyc.*
Arca pulchra ?, *Sow.*
Lucina Bellona, *D' Orb.*
Lithodomus (cast of).
Lima bellula, *Lycett.*
—— proboscidea, *Sow.*
—— lævis, n. sp. ?
—— sulcata, n. sp. ?
—— duplicata, *Sow.*
Hinnites abjectus, *Phill.*
Pecten lens, *Sow.*
—— aratus, *Waagen.*
—— articulatus, *Schl.*
Gervillia acuta, *Sow.*
Perna quadrata, *Phill.*
Pteroperna, sp.
Pinna cuneata, *Phill.*
Ostrea gregaria, *Sow.* (common).
Terebratula submaxillata.
—— ornithocephala, *Sow.*
Rhynchonella quadruplicata ?, *Dav.*
—— Crossii, *Walker.*
Serpula.
Cidaris (rare).
Echinus (rare).
Corals (obscure).

Great Oolite.

Clay below Cornbrash.

Ichthyodorulite (Hybodus ?).
Palate of fish.
Trigonia flecta.
——, n. sp. (near to pullus).
Modiola ungulata, *Y. & B.*
Ostrea Sowerbyi, *Mor. & Lyc.*
—— subrugulosa, *Mor. & Lyc.*
Perna quadrata ?, *Phill.*
Gervillia crassicosta, *Lyc. & Mor.*

Cornbrash.

Ammonites macrocephalus, *Schl.*
—— Herveyi, *Sow.*
Chemnitzia scarburgensis ? (cast).
—— vittata, *Bean.*
Natica, sp. (cast).
Opis, n. sp.
Nucula variabilis, *Sow.*
Astarte minima, *Sow.*
Trigonia Moretoni, *Mor. & Lyc.*
—— flecta, *Mor. & Lyc.*
—— Rolandi, n. sp., *Lyc.*
—— scarburgensis, *Lyc.*
Modiola imbricata, *Sow.*
—— Lonsdalei, *Mor. & Lyc.*
—— gibbosa ?
—— Sowerbyi = plicata.
Goniomya V-scripta, *Sow.*
Myacites modica, *Bean.*
Myacites decurtata (var.).
——, sp.
——, sp.
—— sinistra, *Agass.*
—— calceiformis, *Phill.*
Lucina burtonensis ?
—— Lycetti = crassa.
Isocardia nitida, *Phill.*
——, sp.
Cypricardia, sp.
Corbis rotunda ?, *Walton.*
Corbicella bathonica ?
Arca (rare).
Gresslya.
Pholadomya Murchisonæ, *Sow.*
—— acuticosta, *Sow.*
Cardium Stricklandi, *Mor. & Lyc.*
—— semicostatum, *Phill.*

Cardium cognatum ?, *Phill.*
Lima rigidula, *Phill.*
—— duplicata, *Sow.*
Pecten lens, *Sow.*
—— rigidus, *Sow.*
—— articulatus, *Schl.*
—— inæquicostatus, *Phill.*
—— hemicostatus, *Laube.*
—— subfibrosus, *D'Orb.*
Perna obliqua, *Walton.*
Gervillia acuta, *Sow.*
—— ovata.
Avicula echinata, *Sow.*
Terebratula lagenalis, *Schl.*
—— obovata, *Sow.*
Rhynchonella concinna (dwarf).
Serpula.
Echinus.

Appendix. By R. Etheridge, Esq., F.R.S., F.G.S.

Mr. Cross's long-continued investigation into the geological structure and palæontological features of the Lias and Oolite of the N.W. of Lincolnshire has resulted in obtaining and adding many new species to the fauna of the Lower Lias, and some to that of the Inferior Oolite. We now purpose figuring and describing 6 species—3 from the ironstone beds of the Lower Lias of Scunthorpe, and 3 from the Inferior Oolite of Santon, or the Santon Oolite of the author. Forms of Ammonites new to Britain, but occurring in the same horizon in France, have been discovered and catalogued in Mr. Cross's paper, thus tending to show and correlate through this family of Cephalopoda the close affinity of the Lias of France with that of England through forms or species long looked for. To the species now figured Mr. Cross had already given MS. names, which I retain, but he did not describe them. An extremely rich fauna occurs in this Lower-Lias iron-ore-bearing series of Scunthorpe. No less than 37 species have been found by Mr. Cross, and those chiefly, if not entirely, from the zone of *Ammonites semicostatus*, Y. & B., or *A. geometricus* of Oppel, characterized also by the presence of *Cardinia gigantea*, *C. concinna*, and *C. copides*. The extensive workings carried on through the mining for and extraction of the iron-ore at Scunthorpe has necessarily opened out a great area, which has not been lost upon the author of this able paper, to which I have added the following notes.

The forms to be noticed are 1 species of *Hippopodium*, 2 of *Tancredia* from the Lower Lias, 2 species of the genus *Cucullæa*, and 1 *Astarte*.

Tancredia, Lycett, 1850.

(*Hettangia*, Terquem, 1852.)

The genus *Tancredia* was established by Dr. J. Lycett in 1850, to receive a peculiar group of shells occurring in the Inferior and Great Oolite of this country, *T. donaciformis* being the type. Terquem and Buvignier have determined 12 species from the Lias of France, none of which appear to be the forms here figured. The species of this genus had but a limited range in time; hence they are important to the stratigraphical geologist. Hitherto, of the 20 species known in Britain, only three have occurred in our Lower Lias, viz. *T. ovata*, *T. securiformis*, and *T. tenera*. These donaciform shells are all destitute of any ornamentation.

Tancredia ferrea (Cross, MS.), Ether. Pl. V. fig. 4.

Shell ovately trigonal, donaciform, elongated, acutely pointed at the anterior extremity; umbones small, depressed and slightly incurved; posterior side, gaping extremity acute and incurved; postero-dorsal edge slightly convex, and having a depressed concave space or band, bounded by angular sides or ridges proceeding from the umbo to the acute extremity, edge reflected inwards or infolded; antero-dorsal edge straight, with a groove along the hinge-margin, which proceeds from the umbo nearly to the anterior end, edge or margin also infolded; ventral margin convex or elliptically rounded; hinge complicated, lateral tooth large, posterior, and approximate; lateral tooth of left valve projecting; anterior tooth small and under the umbo, lines of growth faint or indistinct, shell smooth, no ornamentation; neither muscular scars nor pallial impressions visible in our specimens.

Affinities.—This shell closely resembles *Hettangia* (*Tancredia*) *ovata*, Terq. and Piette, Mém. Soc. Géol. France, "Lias inférieur de l'est de la France," t. 6, f. 8, 19, also figured by Chapuis & Dewalque, Mém. de l'Acad. de Brux. t. xxv., "Foss. Terr. Jurass." p. 173, t. 25. f. 2. Our shell, however, is less deltoid in form, being more elongated, and the anterior extremity much more acute; it differs from *Hettangia broliensis*, Buv., Pal. Dept. de la Meuse, p. 14, t. 10. f. 22, 23.

Loc. Scunthorpe. *Formation.* Lower Lias (Ironstone series.)

Tancredia liassica (Cross, MS.), Ether. Pl. V. figs. 5, 5 *a*.

Shell donaciform, elongated, slightly rounded or subacute at the anterior end, which is broad and ventricose; antero-dorsal edge or slope straight and angular; the depressed area or space extending from the umbo to extreme anterior end is narrow; the inner edge of this area is rounded, the outer very acute; posterior extremity elongated or attenuated; umbones nearly central, slightly incurved; ventral margin or border rounded, and much the deepest at the anterior side.

This shell differs from *T. ferrea* in its greater depth and obtuseness anteriorly; it is also more attenuated posteriorly, and the teeth are smaller in proportion to the size of the shell than in *T. ferrea*. The anterior extremity of *T. ferrea* is acutely pointed, in *T. liassica* rounded or obtuse. I cannot refer it to any continental form; both this and *T. ferrea* are quite distinct from any known species.

Loc. Sheffield Hill. *Formation.* Lower Lias (*Pecten*-bed).

Fam. CYPRINIDÆ.

Hippopodium, Sowerby, 1819.

This remarkable genus occurs only in the Lias, the type *H. ponderosum* being somewhat abundant in the upper part of the Lower Lias, associated with *Ammonites raricostatus*, Zieten, *A. armatus*, Sow., and *Thecocyathus rugosus*. This species comes from a lower horizon, viz. the upper portion of the zone of *A. Bucklandi*, where it is associated with *A. semicostatus* and the *Tancredia* described above (*T. ferrea*).

HIPPOPODIUM FERRI (Cross, MS.), Ether. Pl. V. figs. 6, 6 *a*.

Shell oblong, thick and ponderous, obtusely truncated anteriorly, rounded posteriorly, dorsal edge arched or slightly convex, ventral margin sinuated; umbones large, thick and incurved, hinge-line thickened, especially near the umbo; lines of growth following the sinuosities of the ventral margin. The characteristic oblique tooth is not clearly observable in our specimens, owing to the matrix covering it up; neither are the muscular scars or pallial line.

Affinities and Differences.—This shell differs essentially from the type *H. ponderosum*, being much more acute at the posterior end, less ponderous, and less rugose.

Loc. Scunthorpe. *Formation.* Lower Lias (Ironstone series).

CUCULLÆA ROLANDI (Cross, MS.), Ether. Pl. V. fig. 3.

These small *Cucullææ* are at all times difficult to name, age having much to do with specific determination; but there is that about the above-named form which prevents us from confusing or identifying it with any known species.

Shell small, rhomboidal or quadrate, equilateral and convex; umbones central, moderately large, nearly touching anterior side; broadly rounded; posterior side with an obtuse carina and flattened space; ventral margin convex and smooth; hinge-line straight, narrower than shell; area lanceolate, marked by 5 divaricating striæ or lines; lateral hinge-teeth four or five on either side of umbo, horizontal; none on the median or central portion, which is thin and well defined. Surface of shell faintly marked by lines or plications of growth.

This shell differs from *C. santonensis* in the structure and arrangement of the dental system, in not having any reticulation upon the posterior side near the umbo, and in the absence of central teeth along the hinge-area between the lateral teeth.

Affinities.—The rounded equilateral and obtuse form and umbo of this shell resembles that of *Limopsis*; but the horizontal and less numerous teeth remove it from that genus; with no known *Cucullæa* can I correlate it. A shell named *C. fabiformis* by Terquem and Jourdy, from the Great Oolite of Les Classes (Dept. Moselle), resembles our *C. Rolandi* in some respects; but the hinge-line is straighter and longer, and the shell more quadrate.

Loc. Santon. *Formation.* Inferior Oolite.

CUCULLÆA SANTONENSIS (Cross, MS.), Ether. Pl. V. f. 2, 2 *a*.

Shell obtuse or quadrate, inæquilateral; umbones nearly central, contiguous; area beneath umbones narrow and traversed by three divaricating obtuse-angled ridges; lateral teeth 5, strongly defined and slightly inclined; central or median teeth 3, and small. Posterior side truncated; ventral margin smooth and thin; hinge-area or line much narrower than the width of the shell along ventral border, owing to the posterior side being more produced or elongated. Exteriorly the shell seems to have been minutely reticulated, coarsely on the posterior side of the umbo, the anterior being nearly smooth.

The numerous figures of species of this genus given by continental authors do not aid me in referring this form to any known species; and although this and *C. Rolandi* are small shells, they are evidently mature in age, the thickness of the shell, development of the dental system, and markings on the shell attesting this; and no *Cucullææ* in the Inferior Oolite of the west or south-west of England resemble them.

Loc. Santon. *Formation.* Inferior Oolite.

ASTARTE.

Abundant as the species of *Astarte* are in the Oolites of England, Mr. Cross has found and determined another form distinct from any thing yet known; and small as the specimen is, it appears to be a mature shell. The type is remarkable, and must be rare, as no kindred species has yet occurred in our Lower Secondary rocks. We possess only one valve of this interesting shell.

ASTARTE DIVARICATA (Cross, MS.), Ether. Pl. V. fig. 1.

Shell inequilateral, small, ovately trigonal, as broad as long; umbo acute; inner edge of valve ornamented by a row of minute dot-like tubercles or denticulations, which extend from anterior to posterior adductor-muscular scars. Outer surface marked with divaricating costæ or ribs, 12 or 14 in number, reckoning the divarication from the umbo to the centre of the ventral edge; the line of divarication commences near the umbo, and extends to the centre of the ventral border; both on the anterior and posterior sides or edges of the shell the ribs are strongly crenulated or folded, especially on the anterior side, where they are almost spinose; the surface of the costæ is ornamented with delicate striæ at right angles to them, the delicate lines passing over and between the ribs.

Had this been a *Pecten* instead of an *Astarte*, we should not have ventured to thus notice it, fearing that the other or opposite valve might have been very different; but as both valves in *Astarte* possess the same ornamentation it little matters. Our valve being a left one, we can only judge of the anterior tooth in the right by the corresponding pit in the left, which evidently received a long and deep tooth.

Loc. Santon. *Formation.* Inferior Oolite.

EXPLANATION OF PLATE V.

Fig. 1. *Astarte divaricata*, sp. n. Twice natural size.
2, 2 *a*. *Cucullæa santonensis*, sp. n. Twice natural size.
3. *Cucullæa Rolandi*, sp. n. Natural size.
4. *Tancredia ferrea*, sp. n. Natural size.
5, 5 *a*. *Tancredia liassica*, sp. n. Natural size.
6, 6 *a*. *Hippopodium ferri*, sp. n. Natural size.

Discussion.

Mr. Etheridge spoke as to the excellence of the paper, which contained a most useful collection of facts. Two of the species of *Ammonites* exhibited were rare, being new to Britain, and only previously known in France and Germany, showing and confirming the wide distribution in space of certain forms of this group. An important feature in Mr. Cross's paper consisted in his determining and correlating the zones of life in his area with those of the south and west of England, especially as regards the lowest part of the Lower Lias. The fixing the true position of the Frodingham ironstone and its associated fauna, fully establishing its place, thickness, and value, and finally settling the point at issue as to its being on the same horizon as the "Cleveland seam," is also of high importance.

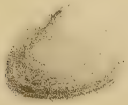
Mr. Judd remarked on the interest attaching to this communication, not only as describing a district little known to geologists, but also as furnishing us with evidence of very fine developments of geological horizons which elsewhere in this country are represented only in a very imperfect manner, or not at all.

Mr. J. F. Blake remarked that though the author had found no exposure of beds between the *angulatus*-zone and the Keuper, they probably existed, as they occurred both to the south and to the north in Yorkshire, across the Humber. He agreed with the author that the ironstone of Lincolnshire was on an entirely different level, and was totally unrelated to that of Yorkshire, the true equivalent of which, though here only 8 feet, was much thicker, though not of any commercial value, across the Humber. The *Pecten*-beds mentioned were characteristic of the same zone in Yorkshire as in Lincolnshire; but in the former county they contained no iron except in the form of pyrites. The thinness of the upper beds as contrasted with the thickness of the lower, showed a veritable thinning-out of them, which was continued into Yorkshire, where some of the fossiliferous bands of the Inferior Oolite described by the author appear to be altogether wanting.

Prof. Hughes said that he thought we should be careful not to infer too hastily an interruption in the continuity of deposition from the absence of certain fossils from the horizon at which they occur in other sections.

1

2

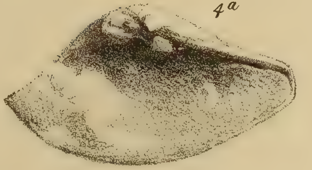


3

2a

4

4a



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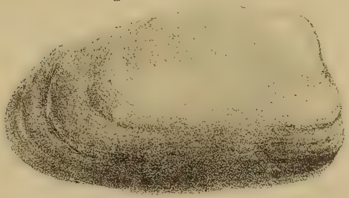
5

6



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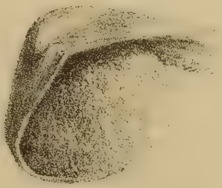

C.R.Bone, del.et lith.

M.&N.Hanhart imp.

LINCOLNSHIRE JURASSIC FOSSILS

10. *On the* STRUCTURE *and* AGE *of* ARTHUR'S SEAT, EDINBURGH.

By JOHN W. JUDD, Esq., F.G.S. (Read January 27, 1875.)

EVERY geologist is familiar with the features presented by the remarkable group of hills on the outskirts of the city of Edinburgh, and is aware of the important part which their rocks have played in the controversies of Neptunists and Plutonists, of Huttonians and Wernerians. In discussing the origin of certain of the phenomena presented at Arthur's Seat, and the evidence which these afford of the period of its formation, it will be unnecessary to notice at length the numerous important contributions to our knowledge of the geology of the hill which are to be found in the works of the older controversial writers *. Our retrospect of the previous literature of the subject need not, indeed, go back further than the time of Charles Maclaren, to whom is undoubtedly due the merit of demonstrating that in Arthur's Seat and the surrounding hills we have the relics of an ancient volcano.

The results of Maclaren's patient studies and ingenious inferences on the subject were given to the world in a series of letters in the 'Scotsman' newspaper in 1834, and were embodied in his well-known work 'The Geology of Fife and the Lothians,' published in 1839. I shall not be exaggerating the merits of this valuable and original work in attributing to it a most important influence on the progress of our science. The descriptions of Maclaren's work are a model of accuracy and clearness; and nothing can be more admirable than the bold ingenuity, tempered by modest caution, with which he traces out the causes to which the complicated structure of Arthur's Seat owes its origin.

Since the appearance of Maclaren's work a number of valuable observations on the district have been published, especially by the officers of the Geological Survey and by the members of the Geological Society of Edinburgh. Foremost in importance among these must be reckoned the proof, resulting from the accurate mapping of the district, that the rocks of the Calton Hill are simply a portion, separated by a fault, of the mass constituting the Arthur's-Seat group †.

The study of the structure of these hills suggested to Maclaren a theory of their mode of formation which has been adopted, in all its essential details, by Prof. Edward Forbes, Prof. Archibald Geikie, and other observers. According to this theory, the rocks of Arthur's

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* It will scarcely be right, however, to pass over this subject without a passing reference to such names as those of Hutton, Playfair, Sir James Hall, Boué, and Jameson, among the founders of geological science, or to those of Walker, Williams, Townson, Allan, Rhind, Milne-Home, Hay-Cunningham, Dr. Hibbert, Lord Greenock, and Professor Fleming among the students of the details of Edinburgh geology.

† See Memoirs of the Geological Survey: 'The Geology of the Neighbourhood of Edinburgh' (1861), p. 26.

Seat were produced by *two entirely distinct series of volcanic outbursts* upon the same site, the interval between which was marked by the deposition, the subsequent upheaval, and the removal by denudation of at least 3000 feet of Carboniferous strata.

That the earliest of these periods of volcanic eruption was contemporaneous with the deposition of the lower portion of that formation to which he gave the name of "the Calciferous Sandstone"—a term now very generally adopted by geologists—was clearly perceived by Maclaren. He did not, however, succeed in obtaining any data for fixing the age of the supposed *later* series of volcanic outbursts.

In 1854, Edward Forbes, coming to Edinburgh fresh from the study of those lavas in the Western Isles which the researches of the Duke of Argyll and himself had proved to be of *Tertiary* date, originated, though he did not publish, the suggestion that the supposed newer volcanic eruptions of Arthur's Seat might also have taken place during the same epoch.

In preparing the one-inch map of the district with the accompanying memoir of the Geological Survey, Prof. Geikie, who has given so much attention to the geology of the district, adopted in 1861 this opinion of the *Tertiary* age of the rocks in question as the probable one [*]; at a later date the *Secondary* age of these rocks was suggested by the same author [†]; but in 1867 both of these views were abandoned in favour of the opinion that they are of *Permian* date [‡].

While studying, during several years past, the volcanic rocks of Edinburgh, in connexion with those of other parts of Britain, I have been gradually led to the conclusion that the supposed second series of volcanic outbursts at Arthur's Seat—the suggestion of even a probable date for which has proved so perplexing a problem for geologists—really had no existence; but that, on the contrary, all the phenomena of the district are capable of being explained on the hypothesis of a single and almost continuous series of eruptions, confined to one geological period—the Lower Carboniferous.

I must here pause, however, to perform an act of justice to the memory of Maclaren. During his later years he had continued his patient researches among the rocks of Edinburgh, visiting, for the purpose of comparison, some of the chief volcanic districts of Europe. The object which he seems to have kept before him was a recast of his original work. But, unfortunately, the preparation of this important task was too long deferred by the talented but cautious author; and although, shortly after his death at the advanced age of 85, a new edition of the work was published, yet it proved to

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[*] Sheet 32 of the 1-inch Map of the Geological Survey of Scotland, and Memoir on the Geology of the Neighbourhood of Edinburgh, &c.

[†] Sheet 2 of the 6-inch Map of Edinburghshire, of the Geological Survey of Scotland (1864). See also the Map accompanying 'The Scenery of Scotland viewed in connexion with its Physical Geology' (1865).

[‡] See 'Brit. Assoc. Rep.' for 1867 (Dundee Meeting), Trans. of Sect. p. 51, and subsequent publications.

be little more than a reprint of the former one. A few notes and additions nevertheless serve to indicate some of the modifications or developments of the author's opinions.

It was after I had arrived at the conclusion already enunciated, that only one series of volcanic eruptions had taken place at Arthur's Seat, that I found in the second edition of 'The Geology of Fife and the Lothians,' page 47, the proof that Maclaren had himself abandoned his original views upon the subject. After the passage from his former edition on the second series of eruptions, he adds in 1866, "Such was my opinion in 1839. I am now satisfied that the trap-tuff constitutes only one deposit, and that the second period of eruption after so long an interval had no existence."

It will not be necessary to apologize to this Society for bringing before it new observations, and deductions from them, on a district so intimately associated with some of the most important movements in the history of our science as Arthur's Seat. And if I may be permitted to be the interpreter of the latest and posthumous ideas of one to whose writings I am so much indebted for instruction as Charles Maclaren, it will be to me a source of no small gratification and pride.

In seeking to explain the structure of Arthur's Seat, there are three classes of objects which the geologist may with advantage appeal to for purposes of comparison and illustration. These are as follows:—

I. The numerous volcanic vents in a similarly ruined condition to Arthur's Seat, which are found scattered all over the districts of Forfar, Fife, and the Lothians. Nowhere, perhaps, can the phenomena connected with these old centres of eruption during the Carboniferous period be so admirably studied, in association with one another, as in the group of hills overlooking Edinburgh; but, nevertheless, many of the neighbouring vents will be found by the geologist to illustrate in an especially clear manner some particular point of their common structure.

II. The Tertiary volcanoes of the Hebrides, which, as I have recently pointed out to this Society, are so admirably dissected by denudation, furnish us with a kind of middle term between the fossil volcanoes of Central Scotland and those which we still see in a state of activity. Viewed in this light, as affording a link by means of which we may more easily compare a series of volcanic skeletons with another of perfect volcanoes, such small denuded cones as Beinn Shiant in Ardnamurchan are of especial interest.

III. In many districts where active or but recently extinct volcanoes abound, we cannot fail to recognize, in spite of their different states of preservation, numerous counterparts of structure, similarities of relation, and identity of materials with the old Carboniferous volcanic tracts of Central Scotland.

In approaching the study of this question it will be well, in the first place, to eliminate all those portions of the subject concerning the interpretation of which no difficulties now any longer exist. Fortunately, these are by no means inconsiderable; for concerning the structure of the western and basal portions of this group of hills all geologists are now perfectly agreed.

The *foundations* of Arthur's Seat and Salisbury Craig consist of rocks belonging to the lower part of the Calciferous Sandstone series, sandstones and shales of estuarine origin, alternating with deposits of stratified volcanic tuffs, and streams of basaltic and felspathic lava. Between these lower beds of sandstone, shale, &c. at least three great sheets of doleritic lava have been injected, which, in consequence of their greater relative capability of resisting denuding influences, now constitute the three bold escarpments known as the St. Leonard's, Salisbury, and Bog Craigs (the latter of which is also called the Dasses). Above this foundation of sandstones and shales, with interbedded and intrusive volcanic materials, a somewhat complicated mass of rocks rises, consisting of lavas, in currents * and dyke-like masses, with layers and piles of volcanic agglomerates.

All these rocks at the base of the Arthur's-Seat hills have a dip to the E.N.E. averaging about 20°; and nothing can be clearer than the fact that they form a part of one of the great anticlinal folds into which the whole of the strata of this district have been thrown. Another fact which has been recognized by all geologists who have studied the district is, that the lower rocks of Arthur's Seat must have been buried under *at least* 3000 *feet* of the higher Carboniferous strata, similar to those which are still seen occupying the bottoms of the synclinal troughs on either side of them, and which have evidently been removed from the summits of the anticlinals by denudation.

Such, then, are the points on which all are agreed. Let us now turn to those conclusions which we regard as open to question. According to the generally received hypothesis of the structure of the hill, the higher masses of rocks constitute a great unconformable "cake," of far later date than the basal portions of the hills, and laid down upon these subsequently to their upheaval and denudation. The grounds of this conclusion we shall now proceed to examine.

At the outset of this portion of the inquiry, however, we may notice the remarkable fact that no geologist has succeeded in pointing out any distinction whatever, either in their petrological characters or their state of preservation, between the lavas of the basal and upper portions of Arthur's Seat respectively. The basalts of Whinny Hill, for example, present no features whereby they

* One of the lava streams in this portion of the series affords an interesting example of a most characteristic volcanic structure, which, strange to say, appears to have been hitherto quite overlooked. I refer to the mass called the Long Row, which overhangs St. Anthony's Valley or the Dry Dam, in which we find a basaltic lava current, the lower portion of which is divided into rude vertical columns of large diameter (the base presenting the usual highly vesicular or scoriaceous characters), while the upper part of the same current is made up of smaller curved and interlacing columns passing in places into an amorphous mass. Though less regular and pronounced, the structure of this lava stream is identical with that which gives rise to the beauties of Staffa, and is so frequently exhibited in the Auvergne and other volcanic districts. The nature and origin of this structure has been discussed by Mr. Scrope. See 'Volcanos,' p. 94.

may be discriminated from that forming the apex of Arthur's Seat; while the porphyritic dolerite with large grains of olivine and crystals of augite, seen under Duddingston churchyard, is so precisely similar to that capping the Lion's Haunch, that Maclaren supposed them to have been parts of the same lava current*.

In explaining the structure of the eastern part of Arthur's Seat, Professor Geikie introduced some changes into the original theory of Maclaren, which, however necessary they may appear, must be admitted to increase very greatly the antecedent improbability of the hypothesis of the two distinct periods of volcanic outburst †. According to the amended explanation suggested by Professor Geikie, the outbursts in both the older and newer periods must have commenced with the emission of basalts, and have been continued by that of porphyrites, the successive products of either period being admitted to be severally undistinguishable in character.

The series of events which we are thus required to believe took place in this district is therefore as follows:—

A. At the point where the Arthur's-Seat group of hills now rises, a series of volcanic eruptions occurred during the Lower-Calciferous-Sandstone period, commencing with the emission of basaltic lavas and ending with that of porphyrites.

B. An interval of such enormous duration supervened as to admit of:—

- *a*. The deposition of at least 3000 feet of Carboniferous strata.
- *b*. The bending of all the rocks of the district into a series of great anticlinal and synclinal folds.
- *c*. The removal of every vestige of the 3000 feet of strata by denudation.

C. The outburst, after this vast interval, of a second series of volcanic eruptions upon the *identical site* of the former ones, presenting in its succession of events *precisely the same sequence*, and resulting in the production of rocks of *totally undistinguishable character*.

Are we not entitled to regard the demand for the admission of such a series of extraordinary accidents as evidence of the *antecedent improbability* of the theory? And when we find that all attempts to suggest a period for the supposed second series of outbursts have successively failed, do not the difficulties of the hypothesis appear to be overwhelming? As we have already seen, the opinions of the Tertiary and Secondary epochs as the date of the second series of eruptions have both been abandoned; and now they are doubtfully referred to the Permian, on the ground that volcanic eruptions took

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* I do not propose to digress from the main object of this paper in order to discuss the true nature of the rocks of Arthur's Seat, as deduced from their chemical constitution and petrological characters. In a valuable paper recently published in this Journal (vol. xxx. p. 553), Mr. Allport has described several of them. Here I shall content myself with referring to the rocks of the basaltic class as "dolerites" or "basalts," and those of the trachytic class as "porphyrites." The latter were called porphyries by the older authors.

† The Geology of the Neighbourhood of Edinburgh (1861), p. 124, and note; Horizontal Sections of the Geological Survey, Sheet 1 (1862); &c. &c.

place during that period in Ayrshire and Dumfriesshire. I shall not stay to criticise the supposed proofs of the Permian age of these volcanic rocks in the south-west of Scotland, though they are far from being complete and conclusive. But I may ask, is it at all in accordance with what we know of the physical and palæontological relations of the Carboniferous and Permian formations to admit the probability of such a grand series of operations as that to which we have referred having taken place in the interval between them, while so little change has been produced in the infinitely longer subsequent periods?

Such, then, are the *a priori* difficulties in the way of our acceptance of the two periods of eruption of the rocks of Arthur's Seat. Let us now inquire if this violent hypothesis be really necessary for the explanation of the structure of the hill. That such is not the case, I propose to demonstrate,

First, by pointing out that the supposed proofs of the second period of eruption break down upon re-examination; and

Secondly, by showing that all the phenomena of the district are capable of much more simple and easy explanation on the hypothesis of a single series of volcanic outbursts.

The grounds upon which a second period of volcanic eruption has been inferred in the case of Arthur's Seat are fourfold:—

1. The *vertical* position of the central column of lava which constitutes the apex of the hill, when contrasted with the uptilted beds at its base.

2. The difference of character between the stratified tuffs in the lower part of the hill and the unstratified agglomerates of its higher portion.

3. The *unconformity* supposed to exist between the upper masses of lava and agglomerate and the lower series of sandstones, tuff-beds, lavas and intrusive sheets.

4. The position of an alleged "neck" from which the great mass of lava capping the Lion's Haunch is supposed to have flowed.

I shall now proceed to show that neither of these supposed proofs of a second period of eruption will bear the test of careful examination.

I. With regard to the supposed vertical position of the great central column of lava, I may remark that the phenomena so admirably described by Maclaren—namely, the manner in which the basalt of the apex can be traced, passing down through, and giving off veins into the mass of agglomerates—while they demonstrate the lava to be an intrusive column, do not prove its *vertical* position. There is, in fact, nothing whatever in the appearances described in any way inconsistent with the supposition that this intrusive column, originally vertical or nearly so, may by its subsequent movement, in common with all the surrounding rocks, have been thrown some 20° from its original position.

And, on the other hand, there *are* features in the structure of this lava column which it is very difficult indeed to understand, unless we accept the conclusion that it has partaken of the same movements as those which have affected the subjacent rocks of the hill. Thus, standing on the western side of the hill, and looking up at the apex, along the line of the valley of the Hunter's Bog, no observer can fail to notice that the great intrusive mass of the apex presents that pseudo-stratification so common in large igneous masses, and which is, in this case, combined with a tendency to a rudely columnar structure. But the interesting point about the apex of Arthur's Seat is this, that its pseudo-strata are inclined at precisely the same angle as the intrusive sheets of Salisbury Craigs and all the lower rocks of the hill. This interesting circumstance was noticed by Maclaren, and it is, indeed, well represented in one of his diagrams illustrating the structure of the hill (see 'Geology of Fife and the Lothians, 1st edit. p. 14, fig. 6); he does not appear, however, in 1839, to have recognized its remarkable significance.

Great masses of igneous rocks of all kinds—granites, gabbros, dolerites and trachytes—frequently exhibit this peculiar pseudo-stratification, which, when seen in its most complete form, presents the appearance of more or less curved sheets of rock concentrically arranged. But the parallelism of the pseudo-strata of the apex of Arthur's Seat with the inclined beds all around can scarcely be regarded as accidental; and we cannot but accept it as an indication that this central intrusive mass has partaken of the movements which have affected all the surrounding rocks*.

II. In opposition to the view that the contrast in character presented by the stratified tuffs at the base of the hill, and the coarse unstratified agglomerates of its upper part, points to difference of age, I may remark:—

1. That precisely similar variations are frequently displayed by the products of a single volcano, and sometimes, indeed, by different portions of the materials thrown out during the same eruption. This fact is a familiar one to all who have studied the structure of the volcanoes of the Campi Phlegræi, and is even still more strikingly illustrated in those of the Island of Ischia. The nature of the volcanic agglomerates is evidently determined, in the first place, by the characters, dimensions, and condition of the fragments falling at any point; and in the second, by the circumstances of their becoming agglutinated where they fall, of their being swept along in débâcles of mud (lave d'acqua), or to their being triturated and sorted by waves and currents—according as they are deposited on the land or under water.

2. That the coarse agglomerates and stratified ashes of Arthur's Seat pass into one another by the most insensible gradations, and that in some cases it is impossible to decide to which class a particular

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* Near the celebrated fossiliferous locality of Dura Den, in Fifeshire, a quarry opened in an intrusive mass of dolerite, of probably the same age as the apex of Arthur's Seat, exhibits this pseudo-stratification in a remarkably similar manner. As the mass has slowly cooled, a series of parallel slightly curved planes of division have been produced in its mass, and the mass now presents a pseudo-stratification combined with a rude columnar structure which is almost the exact counterpart of that seen at Arthur's Seat.

portion of the agglomerates should be referred. Of this we have a striking illustration in the fact that certain rocks, classed as unstratified agglomerates in the Survey Memoir published in 1861, are referred to the stratified tuffs in the 6-inch map of 1864.

III. The *unconformity* between the rocks of the upper and lower parts of the hill respectively would seem at first sight to be very clearly proved by the section which is represented in the Survey Memoir (page 23, fig. 5).

1. It must, however, be noticed, in the first place, that the rocks exhibited in this drawing are not presented in a vertical section, but in a slope of about 45°; and, consequently, the appearances do not warrant those conclusions of overlap and unconformability which have been drawn from them.

2. The supposed evidence afforded by this section, as given in 1861, was virtually abandoned in 1864, when, in the 6-inch map, a portion of the supposed overlapping agglomerates are placed (doubtless correctly, as an examination of the spot will prove) with the contemporaneous and interstatified tuffs of the base of the hill.

In order to make this matter clearer, I subjoin a copy of the original drawing, and one of it as now amended in conformity with the 6-inch map of the Geological Survey, representing the relations of the rocks seen beside the Queen's Drive (see figs. 1 & 2).

IV. A mass of lava proceeding from the great basaltic cap of the Lion's Haunch has been supposed by Professor Geikie to represent a "neck" from which lavas flowed during the second period of eruption*.

That this is the true explanation of the appearance referred to I feel the gravest doubt; but if it be so, it seems to be decisive as to the subsequent uptilting of all the rocks composing the hill. A reference to the 6-inch map will show that the elevation of the supposed orifice of the "neck" is about 500 feet above the sea, while the upper edge of the mass, which it is suggested flowed from this orifice, is about 700 feet. Consequently it is clearly impossible that the mass of lava capping the Lion's Haunch could have flowed from this vent and spread around it in its present position, in the manner it is represented to have done by Professor Geikie. But it has long appeared to me that a more probable explanation of the appearances seen above the Queen's Drive is the following:—that a great current of basaltic lava issuing from some point above has filled up a fissure opened in the mass of agglomerates over which it flowed. Dykes thus filled *from above* have been detected not unfrequently in volcanic districts.

Maclaren, indeed, regarded the mass of lava capping the Lion's Haunch as a portion of the same current that is seen below the churchyard of Duddingston, which it unquestionably very closely resembles in its somewhat peculiar mineral characters. If this

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* Memoir on the Geology of the neighbourhood of Edinburgh (1861), p. 124. "The Geology of Edinburgh and its neighbourhood." An address to the Geological Section of the British Association (1871). Reprinted, p. 25.

Fig. 1.—*Section on south side of the Queen's Drive, Edinburgh.*

[Copied from that given in the memoir on the geology of the neighbourhood of Edinburgh (1861), p. 23.]

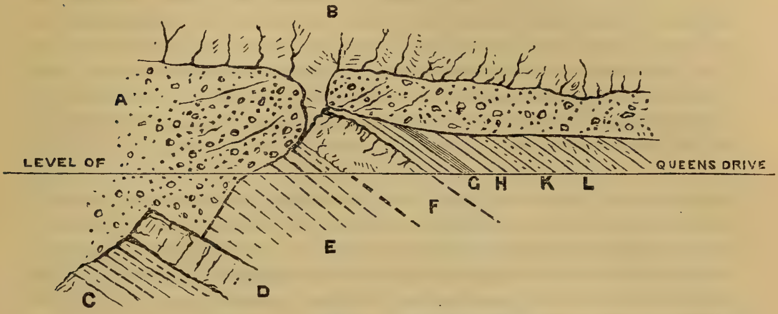
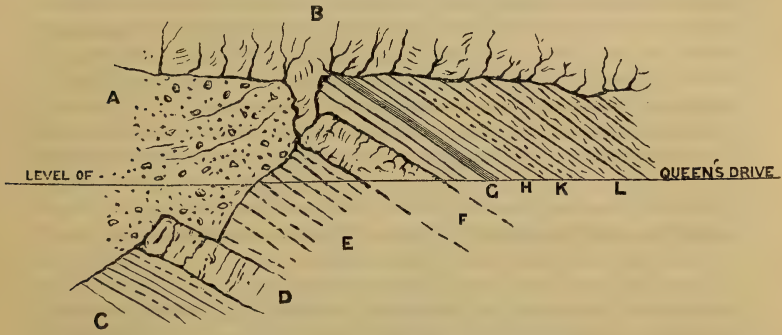


Fig. 2.—*The same Section, corrected so as to conform with the map published in* 1864 (sheet 2 of the 6-inch map of Edinburghshire).



A. Coarse agglomerates &c.
B. Basalt of the Lion's Haunch.
C. Sandstones &c.
D. Intrusive mass of dolerite.
E. Sandstones &c.
F. Doleritic lava stream.
G. Red nodular ash.
H. Red ashy sandstone with marly partings.
K. White cherty limestone, probably overlain by sandstone.
L. Green felspathic ash.

[In examining this interesting section, and weighing the evidence which it affords, it will be necessary to bear in mind that it is not exposed in a *vertical* plane, but in one having a slope of about 45° with the horizontal. We have therefore, even if fig. 1 be the true interpretation of the rocks exposed, no proof of unconformable overlap of the agglomerates A upon the lower beds; the agglomerates *may* occupy a great vertical fissure in the latter. But if, on the other hand, we accept fig. 2 as the true interpretation, the idea of unconformable overlap *must* be rejected, and that of the agglomerates lying in a great fissure be accepted.]

identification could be relied upon, it would, of course, entirely dispose of the idea that the two masses form parts of deposits of widely different ages; for the rock below Duddingston churchyard is clearly one of the contemporaneous lavas in the Lower Calciferous Series. I cannot, however, help feeling that in the several explanations which have been given of the rocks of Arthur's Seat, the local and isolated character of many of the masses of lava have not been sufficiently borne in mind when attempts have been made to identify them by means of their petrological characteristics in different parts of the hill. Thus, I regard the mass of basalt capping the Lion's Haunch, and that of porphyrite which forms the slope leading down from the head of St. Anthony's Valley to Dunsapy Loch, as lava streams that have flowed down the slope of a cone, which, after the manner of modern volcanoes, was doubtless partially destroyed and reformed many times in the course of its history. The present position and prominence of these masses I am disposed to refer simply to their power of resisting denudation, considering them merely eminences capped by portions of hard lava streams analogous to the plateaux of Ischia and the Auvergne, and the Scur of Eigg, though on a much smaller scale.

Having shown that the hypothesis of a double series of eruptions at Arthur's Seat is beset by such grave (I may say, insuperable) difficulties, and that the supposed proofs of it break down on re-examination, let us now proceed to inquire if any simpler theory is capable of satisfying all the conditions of the case.

It has been already remarked that, in studying the volcanic vent of Arthur's Seat, it is desirable to make comparisons, at every stage of the inquiry, with the numerous similar examples of igneous outbursts of the same age in Forfar, Fife, and the Lothians. These present us with a series of Carboniferous volcanoes in every conceivable stage of dissection by denudation.

The Highlands and Borderlands of Scotland are constituted by rocks of the same age, but in very different stages of metamorphism. The great central valley situated between these two mountain-groups composed of Lower Palæozoic strata, is occupied by a series of Newer Palæozoic formations, the positions of which, in relation to the older rocks lying to the north and south of them respectively, appear to be due, in great part at least, to the action of great N.E. and S.W. faults, which have let down the masses of newer strata between those of the older ones.

A new light was thrown upon the structure of the central valley of Scotland when Sir Charles Lyell, nearly fifty years ago*, showed that the Newer Palæozoic strata of the area are bent into a number of anticlinal and synclinal folds, the direction of the axes of which are parallel to the great boundary faults. Later observations, especially those of Charles Maclaren, Mr. Milne-Home, Mr. Powrie, and the officers of the Geological Survey, have shown that the district is also traversed by very numerous faults, maintaining the same N.E. and S.W. direction as the great bounding faults and the axes of

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* Trans. Geol. Soc., 2nd ser. vol. ii. pp. 73–96, plates x. and xi.

folding of the strata. The general tendency of these series of parallel faults, some of which are of great magnitude, has been to bring the *highest* or newest beds into the *lowest* positions in the trough of the Central Valley.

But besides these great series of parallel rolls and faults in the Newer Palæozoic strata of Central Scotland, they are also traversed by a great number of *fissures*, which are filled with various igneous products, and everywhere maintain, with the most striking constancy, the same general direction as the faults and foldings of the strata. In 1824 Sir Charles Lyell described in detail the interesting appearances presented by one of these great fissures, at the Den of the Carity and at other points in the county of Forfar*; and I have recently enjoyed the privilege of studying under his guidance the structure of the whole of that district, to which during more than fifty years he has devoted so much attention.

Leaving out of consideration for the present those older volcanic outbursts, the products of which constitute the Ochil, Sidlaw, Pentland and other similar hill-ranges, we find, in Forfarshire, Fife, and the Lothians respectively, a most instructive series of the products of igneous activity during the Carboniferous period displayed along the great parallel lines of fissure we have referred to, the volcanic structures thus produced being presented to our study in every conceivable stage of unfolding by denudation.

I have spoken of these volcanic outbursts as being of *Carboniferous* age. The remarkable parallelism of the lines along which they are manifested, taken in connexion with the striking similarity of their products, leaves little, if any, room for doubt that they all belong to the same geological period. What that period was, the lavas and ash-beds of southern Fife and the Lothians, so unmistakably seen to be interbedded with the Carboniferous strata, clearly testify.

Of series of volcanic cones evidently arranged along a number of parallel lines, which doubtless indicate the existence of subterranean fissures similar to those of Central Scotland, many examples might be cited among still active volcanic districts. Nowhere, perhaps, is this arrangement better illustrated, however, than in the familiar Campi Phlegræi of Naples.

In the more northern of the districts which we have referred to as exhibiting proofs of these outbursts, that of Forfar, the maximum effects of denudation have been experienced, and we find the various rocks of the Old-Red-Sandstone period traversed by numerous fissures, varying in width from a few feet to several hundred yards; and these, in spite of the drifts, which so greatly obscure the country, can be frequently traced for many miles. The same fissure often varies greatly in width at different points; but sometimes they are found, like ordinary dykes, maintaining a parallelism of walls and constancy of breadth for long distances. These fissures are all filled with the products of volcanic action, either solidified lavas or

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* "On a dyke of serpentine cutting through sandstone in the county of Forfar," Edinb. Journ. Sci. iii. (1825), pp. 112–126.

fragmentary and scoriaceous materials. The former consist of gabbro (often more or less completely altered to serpentine), dolerites, and basalts; the latter of cindery materials, mingled with angular fragments of various rocks, the whole converted, by the deposition of soluble materials (such as quartz and the carbonates of lime, magnesia, and iron) in their cavities, into solid rocks of peculiar and, at first sight, puzzling character. These great fissures or dykes frequently exhibit clear evidence of having been the channels of a succession of volcanic outbursts. In some cases a great mass of fragmentary materials is observed, penetrated by dykes or ducts of consolidated lava; in others a great vertical mass of lava is found to have been rent asunder, and its fissures are seen to be filled with fragmentary materials. In fact, we are enabled to study in Forfarshire those deep-seated phenomena which must necessarily be produced when, as is so frequently the case in volcanic districts, great subterranean fissures are opened, giving passage to liquefied rocks and entangled vapours, by the liberation of which, as they reach the surface, cones of cinders and streams of lava are produced at various points along the line of fracture.

In the second of the districts we have referred to, namely Fife, we may observe another phase of the phenomena of volcanic outbursts. In consequence of the more mitigated action of denudation upon the surrounding rocks, as the result of the positions they have assumed through subterranean movements, we find, not only the great parallel vertical fissures filled with igneous products, but lateral sheets of lava which, failing to reach the surface, have inserted themselves between the planes of the stratified rocks. The interesting phenomena displayed in such cases I have already noticed in a recent paper. Nowhere can the phenomena presented by these great intrusive sheets of dolerite be better studied than in the Lomond Hills of Fife; and a glance at the beautiful map of the Geological Survey will show how numerous and extensive such sheets of intrusive rock are over the whole district.

In the third of the districts we have named, that of the Lothians, still higher portions of the volcanic structures of the Carboniferous period have escaped destruction by denudation. Here, indeed, as well as in Southern Fife, we find portions of these products of igneous activity which actually reached the surface, in sheets of lava, piles of agglomerate, and beds of tuff and ash.

No one studying this series of volcanic fragments in Forfar, Fife, and the Lothians can feel any doubt as to the relationship which they bear to one another. He cannot fail to perceive that, owing to the unequal removal by denudation of their matrices of stratified rocks, different portions of similar contemporaneous volcanoes are exposed to our view. That the dykes and intrusive sheets of Forfar and Fife were surmounted by piles of cinders and currents of lava, is not less certain than that the volcanoes of the Lothians are connected with deep-seated dykes and intrusive masses*.

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* That the rocks of Carboniferous age once spread over far wider areas than those which they at present occupy in Scotland has long been a fact familiar to

If any such doubt did remain in the mind of an observer, concerning the relations of the several phenomena we have referred to, they would be at once dispelled by a study of the structure of Arthur's Seat; for here we find all the appearances described associated with one another in the same mass.

That in Arthur's Seat and the Calton Hill, with the similar volcanic masses of the Castle Rock, Craiglochart, Dalmahoy Craigs, Kirknewton, &c., we have an indication of one of the lines of subterranean fissure running in a N.E. and S.W. direction like those of Forfarshire, no one can doubt. In the doleritic sheets of the St. Leonard's, Salisbury, the Bog, and Girnal Craigs we have manifestations of subterranean volcanic action precisely analogous to those so well exhibited in Fife; while in the lava currents, tuffs, and agglomerates of the central hill, the Lion's Haunch, Dunsapy, and Whinny Hill, we recognize the exact counterpart of similar subaerial volcanic products scattered all over the area of the Lothians.

The apparent complexity in the positions of the rocks composing Arthur's Seat, which at first led to the hypothesis of two periods of eruption separated by an interval of enormous duration, will cease to create surprise, if we bear in mind the nature of the actions to which these rocks owe their origin, and the vast and wonderful system of changes which they have since undergone.

Not a little of the difficulty experienced in seeking to give an explanation of the structure of Arthur's Seat has resulted from attempts to identify different masses of lava at several parts of the hill. If we reflect on the similarity presented in many cases by the different outbursts from the same volcano, the hopelessness of such a task will at once become manifest. On the other hand, when we find the higher portions of a volcanic cone composed of the coarsest agglomerates, while the most finely stratified ashes occur in its outer slopes, the necessity for referring these, in the case of Arthur's Seat, to two widely separated periods will cease to be felt.

With regard to the present positions of the rock-masses of Arthur's Seat, a careful study of them indicates that they have resulted from four distinct sets of causes:—

First. The *original* positions assumed by the outflowing lavas as they issued from the volcanic vent, and of the projected fragmentary materials as they fell around, or were washed down the sides of the cone.

Second. Changes produced by the injection of masses of igneous rock in sheets (that of Salisbury Craigs is in places 80 feet thick!) or dykes.

Third. Changes produced by a central subsidence in the volcanic vent, of which we have so many evidences both in ancient and modern volcanoes. Of such movements I believe I was able to

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geologists. I have, however, recently obtained proof, in a fragment of Carboniferous strata in Morvern, in Argyllshire, marvellously preserved under masses of Secondary and Tertiary rocks, that parts, even of the Highlands, must have been at one time covered by Carboniferous rocks.

Diagrammatic Sections through Arthur's Seat, illustrating the two theories of the mode of its formation.

Fig. 3.—*On the hypothesis of two distinct periods of eruption.*

[Copied from the map in Professor A. Geikie's 'Scenery of Scotland' (1865).]

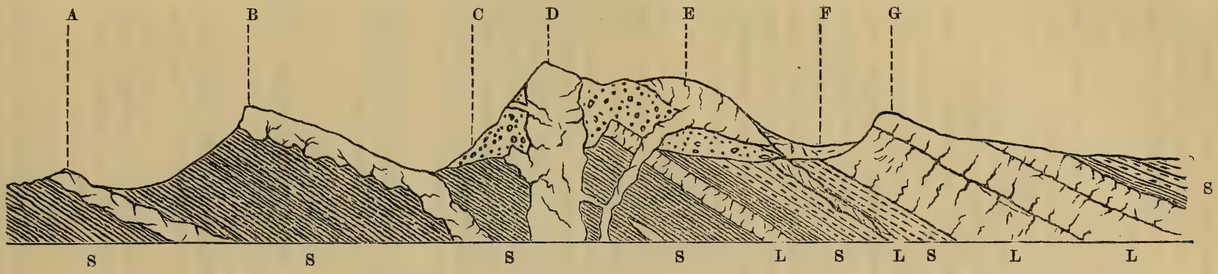
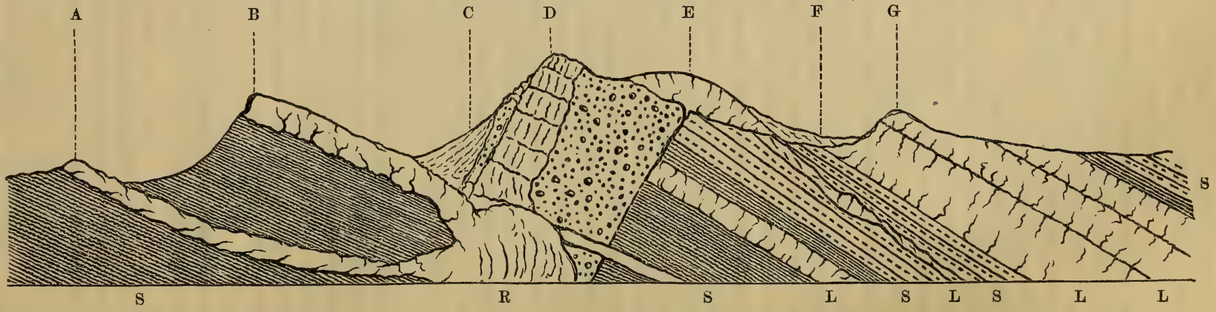


Fig. 4.—*On the hypothesis of a single and almost continuous series of eruptions.*



A. Intrusive dolerite of St. Leonard's Craigs.
B. Intrusive dolerite of Salisbury Craigs.
C. Coarse volcanic agglomerates (with "Talus" in fig. 4).
D. Apex of Arthur's Seat (basalt).
E. The Lion's Haunch, or Nether Hill (lava-stream of porphyritic dolerite).
F. Lava-stream of porphyrite (not strictly in the line of section).
G. Dunsapy.
S. Sandstones, shales, limestones, and "Ash-beds" (stratified tuffs) of the lower part of Calciferous Sandstone series (base of Carboniferous system).
L. Lavas (basalts, porphyrites) alternating with these stratified rocks.
R. (In fig. 4.) Intrusive dolerite of Samson's Ribs, from which the two sheets A and B appear to proceed.

(In order to make the differences between the two modes of interpretation as clear as possible, the section fig. 4 has been constructed on the same scale, and passing through the same points as fig. 3.)

detect traces in studying the great series of rocks on the north side of the Hunter's Bog; and to them must probably be primarily ascribed the remarkable preservation of the fragments of this old volcano as its rocks gradually sank below the sea-level, and were buried under the newer Carboniferous deposits.

Fourth. That grand series of movements to which, in long subsequent times, the whole of the rocks of the district were subjected, and in consequence of which they were bent into those great folds of which we everywhere see such striking evidence.

The fragments both of the subaerial and subterranean portions of this old volcano which have escaped destruction have been determined entirely by their position and durability. The rocks formed *at the surface* have been subjected to *two* periods of denudation, that which elapsed between their formation and their being buried in younger deposits, and that which supervened when the latter were stripped away after the rocks had been brought into something like their present positions by subterranean movements. The *subterranean* intrusions have suffered only during the *later* period of denudation. All the southern portions of the products of this igneous vent, with the surrounding strata, have been entirely swept away, in consequence of their great elevation towards the crown of the anticlinial; consequently in the great scar along which the Queen's Drive is cut, we are enabled to study the contents of the great fissure. Along the northern portions of the group of hills, all the ridges are capped with masses of lava of exceptional hardness and durability.

The history of the formation of Arthur's Seat, briefly summarized, would appear to have been as follows:—

At about the middle of the Calciferous-Sandstone period (Lower Carboniferous) a great fissure opened in the district, began to emit at several points along its course discharges of vapour carrying with them fragments of rock, cinders and ashes, alternating with the outflow of currents of lava. The liquefied products appear to have been both of the basaltic and the trachytic class, or sometimes of that intermediate variety called by Abich "Trachy-dolerite." As in some existing volcanoes, these different products do not appear to have been ejected in any definite order; but periods during which basalts were ejected alternated with others, during which more siliceous lavas were poured forth.

At the same time, probably, with these ejections at the surface, masses of the more liquid materials of the basaltic class found their way along planes of weakness in the surrounding strata, and, instead of being forced out at the surface, consolidated in great subterranean intrusive sheets. Owing to the extensive denudation on the south side of the hill, the connexion of two of these injected masses, those of St. Leonard's and Salisbury Craigs, with the consolidated vertical duct of lava known as Samson's Ribs can still be traced.

That the earlier eruptions of this locality took place in shallow water appears certain, from the nature of the fossils found in the stratified tuffs at St. Anthony's Chapel. Of the exact site of the eruptions giving rise to the earliest of the lava currents, we have no decisive evidence. It seems probable, however, that it was not the point now occupied by the apex of the hill, but some adjacent one on the same great fissure—that, in fact, shifting of the volcanic vent along a line of fracture (a phenomenon so frequently displayed in recent volcanoes) took place in a precisely similar manner in Carboniferous times.

Considerable intervals must have occurred between some of the earlier eruptions of this volcano, as is shown by the deposits of sandstone and shale with which its products are interbedded.

Eventually, by gradual elevation, this submarine volcano became a subaerial one, as is shown by the characters of the agglomerates composing the higher and later portions of its mass*. The changes which were seen to take place in Sabrina and Graham's Isle, and of which we have such unmistakable evidence in the case of Epomeo and Etna, are exemplified in an equally clear manner in the case of the old Carboniferous volcano of Arthur's Seat.

Nor can we fail to recognize a double cause for this elevation of the volcano above the sea-level :—*first*, in the accumulation of the ejected materials around the vent; and *secondly*, in the injection of great sheets of liquefied materials below it.

The extinction of this volcano was probably, as we have already remarked, followed by a certain amount of central subsidence, consequent perhaps on the deflection of the liquefied materials beneath it to other points on the same or neighbouring fissures. Such local movements would doubtless greatly contribute towards the preservation of the hardest and best-protected masses of the volcanic cone, when, slowly sinking beneath the waters of the Carboniferous sea, it was gradually buried under later sediments.

Through the long eras of the Secondary and Tertiary, the vast masses of Newer Palæozoic strata in Central Scotland, with their imbedded ruins of volcanoes, have been gradually assuming their present folded and fractured condition, doubtless in consequence of the operation of those same subterranean forces which in earlier periods were able to force outlets for their violence at the surface. During the same long ages, that equally powerful agency, the circulation of surface-waters, acting ceaselessly and contemporaneously with the igneous forces, was sweeping away and redistributing such portions of the mass as were brought by the action of the latter under its sway. Thus, by the constant *interaction* of antagonistic forces, the final changes in the features and positions of the rocks of Arthur's Seat were brought about. Of these periods, none of the monuments raised at the surface have survived in the central valley of Scotland; but I am seeking to decipher their strange history, in fragmentary and wondrously preserved records in the adjacent Highlands.

* I have found remains of plants in the masses of agglomerate forming the apex of Arthur's Seat. These, however, are too imperfect for identification. As it is possible that they may be ejected fragments of an earlier-formed deposit, like that of St. Anthony's Chapel, they do not afford any aid in the present inquiry.

Such appears to be the series of events to which the rocks of Arthur's Seat owe their origin. It will be interesting, in conclusion, to notice the difference in the mode of preservation of the old volcanoes of Central Scotland, and that of the numerous Tertiary volcanoes the remains of which I have before described as existing in the Hebrides. While the latter owe their survival simply to the hardness or power of resisting denudation of the materials which compose them, the former have been enveloped and protected through long periods in great masses of sedimentary materials. It is through the removal of the matrix of investing strata by denudation that the buried igneous rocks have been once more exposed; and we may therefore justly speak of such vestiges as "fossil volcanoes."

Briefly recapitulated, the results arrived at in the present memoir are as follows:—

1. The antecedent improbabilities of the theory of two periods of eruption for the rocks of Arthur's Seat are exceedingly great, if not altogether insuperable.
2. The supposed proofs of a second period of eruption break down upon re-examination.
3. The theory was found by its sagacious author, as he pursued his investigations among the rocks of Edinburgh and his comparisons with other volcanic districts, to be untenable.
4. All the phenomena of Arthur's Seat are capable of being explained by a much simpler theory, which has, moreover, the advantage of bringing them into exact harmony with the appearances exhibited at many other points in the same district.

Discussion.

Mr. Evans remarked that the simplicity of Mr. Judd's explanation of the phenomena seemed to commend it to the consideration of geologists.

Prof. Ramsay complimented the author on the clearness and elegance of his paper. He said that he had been long well acquainted with the locality described, and had accepted the idea that there had been two periods of eruption, although he had always felt that there were great difficulties attending it; and he was glad that this old idea was now shown to be incorrect. With regard to what the author had said of the lines of faults, he thought that the conglomerates of the southern flanks of the Highlands were unconformable to the older metamorphic rocks.

Mr. Evans inquired whether the evidence is clear as to the sheet of dolerite which crops out at St. Leonard's Craigs not following the direction of the stratification, but cutting through it diagonally.

Mr. Drew inquired how much of the diagrammatic section was from actual observation, and how much from inference.

Mr. Whitaker asked how the basalt on the Lion's Haunch was placed in its present situation.

The Rev. T. G. Bonney said that the configuration of the Hunter's Bog valley had always appeared to him rather to favour the theory of a later date for the cone of Arthur's Seat, that he did not see there was any *à priori* difficulty in supposing a second volcanic outburst in one district after a long lapse of time, and that the volcanic district of West Scotland (so well described by Mr. Judd), and the Cleveland dyke in Yorkshire showed that there had been volcanic disturbances over a large area after Palæozoic times; so that he thought there was something still to be said for the old theory.

Mr. Judd, in reply, stated that the junction of the Highland rocks with the strata lying to the southward was usually very obscure: nevertheless Prof. Nicol had shown that where a clear section was exposed on the coast, the newer Palæozoic rocks were clearly faulted against the older Palæozoic, in the same manner as on the south side of the Central Valley of Scotland. This question was, however, one quite incidental to the line of argument of the paper. Although intrusive sheets of rock usually follow the planes of stratification of the rocks among which they are injected, yet many examples occur of their cutting obliquely across the strata for short distances. He had not attempted to describe all the interesting phenomena of Arthur's Seat, but had devoted his remarks to that part of the subject concerning which the accepted theory did not appear to be satisfactory. He did not deny the *possibility* of later eruptions taking place on the same site as those of a former period, but maintained that the *onus* of proving that such was the case in the present instance lay with those who rejected the more simple theory.

11. *On the* FEMUR *of* CRYPTOSAURUS EUMERUS, Seeley, *a* DINOSAUR *from the* OXFORD CLAY *of* GREAT GRANSDEN. By HARRY GOVIER SEELEY, Esq., F.L.S., F.G.S., Professor of Physical Geography in Bedford College, London. (Read December 2, 1874.)

[PLATE VI.]

THIS femur, presented to the Woodwardian Museum in 1869 by L. Ewbank, Esq., M.A., Clare College, Cambridge, still remains, so far as I have seen, the only example of a Dinosaurian genus from the Oxford Clay which has a general affinity with *Iguanodon.* As in all the Dinosaurs collected from the great Pelolithic period extending from the Oxford to the Kimmeridge Clays, the articular extremities of the bone show in their pitted surfaces evidence of having had terminal cartilages, though these do not appear to have been so thick as to have modified materially the forms of the articular ends. Thus the bone is devoid of epiphyses. And since epiphysial growths among the lower vertebrates have a definite relation to the activity of the animal type in which they are found, as is shown by their occurrence in Anura and Lacertilia, it would seem likely, since Dinosaurs are to a large extent Reptilian in their osteology, that this condition of the articular surfaces bespeaks animals of sluggish habits, and therefore, it may be, of cold blood, notwithstanding that a not dissimilar condition marks the articular ends of bones in the larger Cetacea.

This femur is 1 foot and $\frac{1}{4}$ inch long, with a slight antero-posterior flexure forward in the lower third of the shaft (Pl. VI. fig. 1). The bone is stouter and has its articular ends more expanded, and pertained to a stouter type of limb than the femur of *Hadrosaurus* or any of the figured American Cretaceous Dinosaurs; its articular ends, also, are wider in proportion to its length than in *Scelidosaurus, Megalosaurus,* or *Iguanodon.*

At the proximal end the shaft is triangular in section, being flat on the outside and compressed towards the inside; and the proximal articular expansion extends inward, so as to have an extreme width of $4\frac{1}{8}$ inches. The articular surface may be regarded as consisting of two portions. An inner subspherical part corresponds to the head or ball of the femur (figs. 2 & 3, *b*); it is irregularly subcircular, moderately convex, and looks upward, obliquely forward, and inward: the extreme front-to-back width of this part of the articulation is $2\frac{1}{2}$ inches, though its posterior outline is not regularly convex. The continuous outer portion of the articulation is subquadrate or slightly oblong when seen from above, obliquely concave from within outward, and slightly convex from front to back, where it measures $1\frac{1}{2}$ inch wide, and has the posterior border rounded more than the anterior border. Looked at from the outside the articulation is directed inward and slightly forward, but extends to the limits of the bone. From this long articular surface one might infer that the ilia were not directed upward and inward, converging as among birds, but rather outward as among reptiles, or upward as among some reptiles and some mammals. This condition may also be infered from the ordinary Dinosaurian sacrum, which, widened with transverse processes or bones, is more easily harmonized with that of a mammal or a reptile than with the sacrum of birds.

The great trochanter is a mastiform process (figs. 1 & 3, *a*) partly separated from the anterior side of the bone by a deep narrow groove; in front it is rounded and does not extend so far proximally by $\frac{1}{4}$ inch as the articular surface. The groove or slit is nearly parallel to the posterior side of the bone; it is $1\frac{1}{2}$ inch deep on the outer side of the bone, but not more than $\frac{3}{4}$ inch deep on its front aspect. Between this trochanter and the ball of the femoral articulation the bone is deeply concave laterally (fig. 3). A badly defined ridge extends 8 inches distally from the trochanter, along the front of the bone, inclining obliquely inward so as to make a prominence in the middle of the front of the shaft just below the point of its least diameter from within outward, which measures about 2 inches. Below the trochanter the bone becomes slightly narrower from back to front, and about halfway down the shaft is constricted to $1\frac{5}{8}$ inch, and thence thickens slightly to the bend in the shaft 8 inches from the proximal end. The outer side of the bone becomes less flattened in descending the shaft, and more convex from front to back. The back of the bone is on the whole flattened.

The longitudinal outlines of the bone are externally gently concave, on the inner side much more concave; while anteriorly the outline is bent in the distal third and has its proximal part subparallel to the posterior outline, though below the bend the outlines diverge towards the distal articulation. Below the bend the form of the anterior area is roughly triangular, since the outline widens from the bend towards the distal face, where it measures 4 to $4\frac{1}{2}$ inches from side to side. The inner surface is flattened distally and looks inward and somewhat forward, rounding into the front of the bone. The outer surface is narrow distally and rounds obliquely and convexly into the front.

The characteristic Dinosaurian trochanter on the middle of the shaft is removed by fracture, but was placed entirely on the posterior aspect of the bone, about $4\frac{1}{2}$ inches from the proximal end and $5\frac{1}{2}$ inches from the distal end (figs. 1, 2 *c*). Its fractured base, which measures $2\frac{1}{2}$ inches in length and 1 inch in width, appears to indicate that the trochanter was directed backward: it divides the inner outline of the shaft into two concavities.

The shaft is triangular at the distal end (fig. 4), as at the proximal end, only the wide side distally is the inner side, and the less rapidly and less regularly converging sides form an external angle. The distal articulation forms a right angle with the axis of the shaft. The articular surface is convex from front to back, while from within outward it is very slightly curved, being concave in the middle and convex on each side externally. It has two principal

G. Sharman lith.

M & N. Hanhart imp

CRYPTOSAURUS EUMERUS.

condyles, the larger of which is on the inner side (figs. 1, 2, & 4, *d*); and from this a sharp angular ridge extends towards the trochanter on the middle of the shaft, so as to separate the flattened inner side of the bone from the posterior side. The inner condyle measures 3 inches from front to back, and is 1½ inch wide; it is convex on the posterior aspect, and is separated by an interspace of fully ¾ inch from the second or outer condyle. This interspace constricts the articulation from back to front to 1⅝ inch. The convexity of the second condyle is broken away (figs. 2 & 4, *e*); but the articular part of the bone extends external to and beyond it for 1¼ inch, terminating in a sharp outer angular process. The back of the shaft between the condyles and for several inches above them, is concave in length and concave from side to side, the shaft there measuring only 1¼ inch from back to front. The margin of the articulation is roughened with strong ligamentous attachments.

This genus differs from *Megalosaurus* in having a more compressed shaft and more expanded extremities, in the position of the inner trochanter near the middle of the shaft, and in the small extent to which the external proximal Amphibian trochanter is divided from the shaft.

From *Iguanodon* it differs in wanting the distal *anterior* intercondylar groove characteristic of the bone in that genus, as well as in all the characters which part it from *Megalosaurus*, except the position of the inner trochanter, in which there is a close agreement between *Cryptosaurus* and *Iguanodon*.

EXPLANATION OF PLATE VI.

The letters in all the figures have the same signification:—*a*, Mastiform trochanter; *b*, Articular head; *c*, Inner lateral trochanter; *d*, Inner distal condyle; *e*, Outer distal condyle. The figures are half the natural size.

Fig. 1. Inner aspect of femur of *Cryptosaurus*.
2. Posterior aspect.
3. Proximal articular end.
4. Distal articular end.

12. *The* GLACIATION *of the* SOUTHERN PART *of the* LAKE-DISTRICT *and the* GLACIAL ORIGIN *of the* LAKE-BASINS *of* CUMBERLAND *and* WESTMORELAND. By J. CLIFTON WARD, Esq., Assoc. R.S.M., F.G.S., of the Geological Survey of England and Wales. Second Paper. (Read January 27, 1875.)

[PLATE VII.]

CONTENTS.

Introduction.—In my paper on the "Glaciation of the Northern part of the Lake-district"*, I endeavoured to show that at the period of maximum glaciation all the main-valley glaciers were more or less confluent, and that thus the country was enveloped in an almost continuous ice-sheet, which moved, in the northern part of the district, mainly from north to south. In Pl. VII. C is a continuation southwards of the glacial map brought forward in the previous papers; and a few words must first be said about the distribution of ice-scratches south of the great east-and-west watershed of the district and its import†.

I. TREND OF THE ICE-SCRATCHES AND ITS IMPORT.

The first glance at the map (Pl. VII. C) shows that, as in the case of the northern part of the district, the general direction of the arrows points to a great system of valley-glaciers more or less confluent with one another. One or two exceptional directions will be mentioned presently.

a. *Wastdale.*—From Scafell Pikes (49) as a centre, there are scratches pointing downwards, from heights above 2500 feet, to the north into Wastdale, and to the south into Eskdale. From the head of Mosedale, beneath the Pillar Mountain (24) ‡ and Red Pike (67), there is a similar series, and from the double valley between Yewbarrow (43) and Middle Fell (42). Upon Buckbarrow (41) there are scratches pointing with the valley at a height of 1250 feet; and at a height of 1600 feet, north of and between Buckbarrow (41) and Seatallan (40) the rocks are rounded as if from the N.E. From these facts we may infer as follows:—Wastdale and Mosedale

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* Quart. Journ. Geol. Soc. vol. xxix. p. 422.

† I am indebted to my colleagues, Messrs. De Rance and Hebert, for some of the observed ice-scratches.

‡ See the map in the first paper (Q. J. G. S. vol. xxx. pl. ix.). The two maps may be joined together to form one.

each furnished a large glacier (figs. 2 & 3, Pl. VII. A). After their junction, between Yewbarrow (43) and Lingmell (47), it seems that part of the S.E. side of the compound glacier was pushed over the low col (971 feet) towards Burnmoor Tarn to join the Eskdale valley and glacier (fig. 4). Just beyond the foot of Yewbarrow (43) a very considerable body of ice joined the main glacier from the wide stretch of upland country known as High Fell. This must have much more than made up for the loss of ice just noticed towards Eskdale; and although the valley widens from this point, it would seem probable that the level of the ice was fully 1500 feet above the present surface of the lake (204 feet above sea-level), only quite the summit of the Screes appearing above the ice, and Buckbarrow (41) and the south-westward slopes of Seatallan (40) being covered up (figs. 7 & 9). Westwards the valley opens out considerably; and this great thickness of ice must have spread in proportion, though as it must have met with similar ice-sheets from neighbouring valleys, the thickness of the ice over the low country was probably pretty well maintained.

b. *Langdale, Easdale, &c.*—Upon the eastern side of Bow Fell (51) lies Great Langdale, a fine rocky-sided valley trending eastwards towards the head of Windermere, and divided at its upper part into the two branches forming Mickleden and Oxendale. Glacial scratches occur not only pointing *down* the valley-sides at heights ranging up to nearly 2500 feet, but in several cases *along* the valley-sides at various heights up to 1500 feet, as on Mart Crag (east of Stake Pass), and below the Pike of Stickle (53). From Sergeant Man (55), Pavey Ark (above Stickle Tarn), and Harrison Stickle (53), the glacial grooves run S.E. towards Great Langdale. East of Sergeant Man (55) their course is, from Codale Tarn, eastwards down Easdale, S.E. down Far Easdale and the Greenburn valley*, and S.S.E. along the valley of the Rothay above Grasmere. The high ridge which separates Great Langdale from Easdale is crossed obliquely from the N.W. by scratches, occurring up to a height of 1500 feet†; and through the Blea-Tarn pass, and over Lingmoor and Blake Rigg, a well-marked series of grooves occur running S.E. into Little Langdale.

This distribution of ice-marks clearly shows that all that group of mountains, draining eastwards, from Wrynose along the Bow-Fell range (51) to the Langdale Pikes (53) and Sergeant Man (55), and south-eastwards and southwards from Sergeant Man to Dunmail Raise‡, furnished one great series of glaciers, confluent over the lower parts of the ridges parting valley from valley (Pl. VII. B, figs. 13 & 14). Thus, when Easdale, Far Easdale, and the Rothay valley were filled with glacier ice, the western portion of these confluent streams was pushed over Blea Rigg (56) and Dow Bank

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* Noticed also by Mr. Mackintosh, 'Quart. Journ. Geol. Soc.' vol. xxx. p. 174. The ice-rounding may be observed at higher elevations along this ridge; but the coarse breccia does not retain the scratches.

† The two valleys north of Easdale.

‡ In map of northern part of the district.

(Pl. VII. B, fig. 14), at heights up to more than 1500 feet, to join the Langdale glacier; and the southern side of this great Langdale glacier was caused also to sweep south-eastwards round the Pike of Blisco (52) and pass into Little Langdale, over what is now Blea Tarn, and across Blake Rigg (57) and Lingmoor (58) on either side. To the north of Ambleside, glacial scratches point southwards down the three considerable valleys in which run Stock Gill, Scandale Beck, and Rydal Beck. The result of the southerly course of the glaciers from these valleys and their all becoming confluent above Ambleside, was to cause the ice-sheet sweeping over Grasmere to continue its course in great part straight over Loughrigg Fell (65)*; and thus the whole stretch of low ground, between Wetherlam† on the west, and Wansfell Pike (66) on the east (Pl. VII. D, fig. 22), was swept over by one continuous sheet of ice, which passed on southwards over the present sites of Windermere, Esthwaite, and Coniston (fig. 23), considerably reinforced on the west by ice shed off the eastern side of the Coniston group, the most southerly of the Lake-district mountains.

c. *Eskdale.*—This valley, the head of which lies in a horseshoe-shaped ring of lofty mountains, of which the chief are Scafell (48), Scafell Pikes (49), and Bow Fell (51), has a series of scratches pointing downwards at various heights up to 2500 feet. The great glacier which gave rise to these was also reinforced by ice coming down the head of Duddondale, partly pushed over by Hardknott Castle on the north side of Harter Fell.

d. *Abnormal ice-scratches.*—Allusion must now be made to several cases of ice-scratches having a direction which cannot be readily explained, apparently, by any system of local or confluent glaciers. At the Three-Shire Stone, Wrynose, upon the watershed, at a height of rather more than 1250 feet, there are grooves running due east and west, *i.e.* straight through the pass. A little higher, to the north, on Wet-Side Edge, there are beautifully glaciated rock-surfaces, with scratches pointing E.S.E. and W.N.W., also close upon a watershed. A little south of Cold Pike, at 2000 feet, there are fine scratched surfaces, showing a direction a little E. of N. and S. of W., just on the ridge.

Between Bow Fell (51) and Shelter Crags‡, in a depression of the watershedding-line, and at a height of 2400 feet, there are also glacial scratches having a due east-and-west direction.

At Sty-Head Pass (nearly 1600 feet) there is distinct glaciation across the watershed, apparently from E.N.E. to W.S.W.; and on either side of the pass scratches cross the watershedding line at 2000 feet; on the south side, the direction across the Band (running north from Great End (50)) is nearly due E. and W.; and on the north side, upon the flanks of Great Gable (46), the direction is N.N.E. and S.S.W.

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* The Rev. T. G. Bonney, in 1866, thought that this Fell was once "almost covered by glaciers," see paper "On traces of Glaciers in the English Lakes," Geol. Mag. vol. iii. p. 291.

† Just south of the limits of the map.

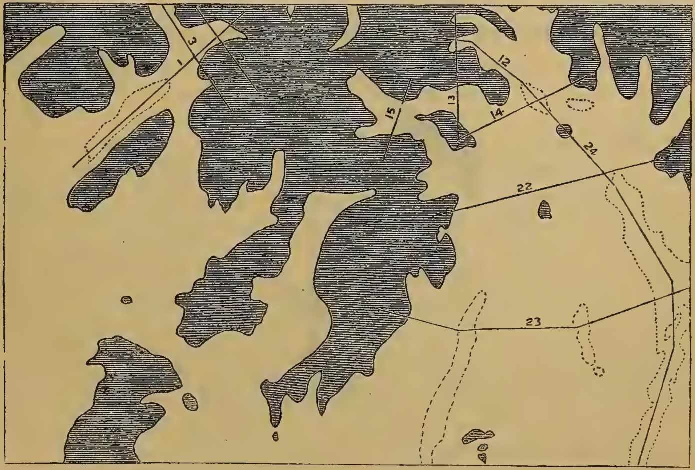
‡ A little to the south of Bow Fell.

Such cases as these here enumerated must either be the result of the ice having so great a thickness as to be fairly above these separate cols or passes, and thus flowing in some instances directly through them, or due to floating ice. I cannot easily conceive how any land ice could produce the grooves across the ridge south of Bow Fell, unless a great sheet was forced across the district from the outside, either from the east or west; and this idea seems quite untenable.

Much more drift is found in the valley on the west of the Wrynose Pass than on the east; and I am strongly inclined to think that during the submergence a current ran from west to east through a Wrynose Strait, and that the cases across Bow Fell indicate that the depression may have reached an amount little short of 2500 feet (woodcut, fig. 4).

During submergence there could be no direct communication between the east and west halves of this southern part of the lake-district until the sea reached the level of rather more than 1250 feet. At 1500 feet, the contour of the country would be as represented in woodcut, fig. 2, the Coniston group being separated from mountains to the north by the Wrynose Pass. In woodcut, fig. 3, the contour at 2000 feet is shown, and in fig. 4 that at 2500 feet. The map in woodcut fig. 1 shows not only what the form of the land might be during a submergence of 1000 feet, but also indicates the area of land once covered by the confluent glaciers, the white parts representing the ice. Fig. 2 might be similarly used*.

Fig. 1.—*Contour-map showing the probable form of the land when the submergence had reached* 1000 *feet.* (Scale 3 miles to $\frac{7}{12}$ inch.)



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* The lines drawn on fig. 1 are those along which some of the principal sections have been taken.

Fig. 2.—*Contour-map showing the form of the land at* 1500 *feet.*

Fig. 3.—*Contour-map showing the form of the land at* 2000 *feet.*

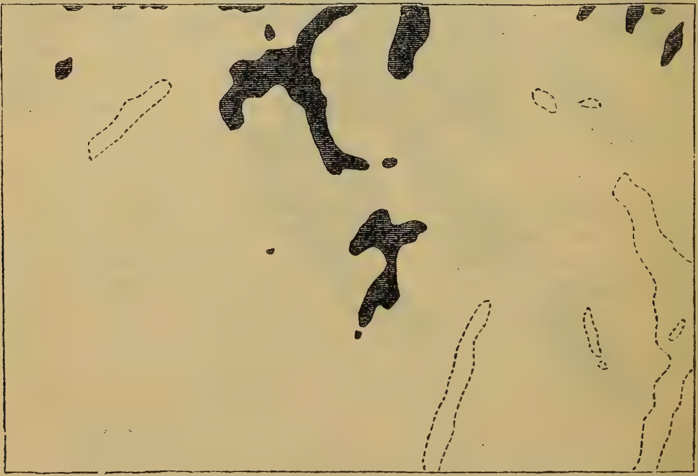
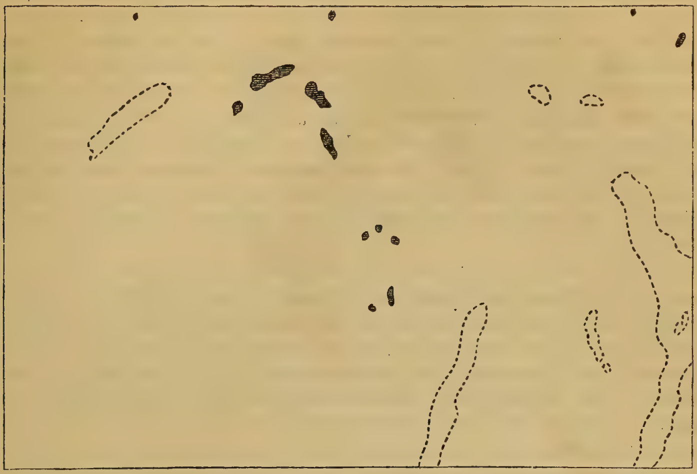


Fig. 4.—*Contour-map showing the form of the land at 2500 feet.*



II. Moraines.

The moraines belong almost exclusively to the late set of glaciers. They occur at the heads of Mosedale, Wastdale, Langdale, and in the Easdale and Greenburn valleys*; also about Angle, Stickle, and Easdale Tarns. Those in connexion wth the tarns will be again alluded to in the sequel.

III. Lake-basins.

In my first paper on the subject of lake-basins†, I discussed the origin of the following Cumberland lakes:—Derwentwater, Bassenthwaite, Buttermere, Crummock, and Loweswater. The facts of the case—the lakes being but long shallow troughs, the thickness of glacier ice which moved along the valleys in which the lakes now lie, the agreement of the deepest parts with those points at which, from the confluence of several ice-streams or the narrowing of the valley, the onward pressure of the ice must have been greatest—seemed to warrant the conclusion "that the immediate cause of these lake-basins was the onward movement of the old glaciers, ploughing up their beds to this slight depth, in the way Professor Ramsay's theory suggests."

I now propose to consider, in a similar manner, the origin of Wastwater, Grasmere, Windermere, and Coniston Water, and Easdale, Codale, and other tarns.

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* Those in the Longstrath and the other valleys to the north of the watershed, and on Stake Pass, have been noticed in a previous paper (Quart. Journ. Geol. Soc. vol. xxix. p. 422).

† Quart. Journ. Geol. Soc. vol. xxx. p. 96.

a. *Wastwater.*—The depth and contour of this lake is given upon a true scale in Pl. VII. A—fig. 1 being a section along its length, and figs. 4–10 transverse sections (see dotted lines on the plan, fig. 11). In fig. 1 the mountains on the north side of the valley are shown with their true heights, and their bases are supposed to be visible through the glacier ice. There is no doubt that the lake once extended as far as Wastdale Head; and this I have indicated by a dotted line (fig. 1). Thus the basin commenced at the junction of Mosedale and Wastdale; and its present deepest part occurs just opposite the point at which the only other tributary valleys (those in which Over Beck and Nether Beck run) join the main one.

I see no reason to suppose that the lake runs along the course of any fault or fissure, although it is possible that a tongue of granite runs from the Eskdale mass at the foot of the lake, beneath the water and alluvium, to unite with that of Wastdale Head. The rocks, however, on either side of the lake, consist of highly metamorphosed volcanic ash traversed by numerous dykes, with the exception of about a mile of the north-western shore at the foot, which is occupied by syenite.

Since the surface of the water is 204 feet above the sea, and the lake is 251 feet deep*, it follows that the bottom is 47 feet beneath sea-level. The soundings show also that for a distance of fully a mile and a quarter the bed of the lake thus lies beneath the sea-level. In the map, Pl. VII. C, a dotted line is drawn along the lake through the points of greatest depth; this line makes two decided curves—one approaching nearest to the north-west shore, at the foot of Bell Rib, Yewbarrow (43), and the other very nearly approaching the steep cliffs of the Screes some little way below the mouths of Over Beck and Nether Beck. This, then, is the contour of the basin, preeminently a rock-basin; how has it been formed?

As several authors have written upon Wastwater, it will be necessary, first of all, to state briefly their views. In 1861, Professor Hull, in some "Notes on the Glacial Phenomena of Wastdale"†, gave it as his opinion that the lake was due to the presence of a terminal moraine, which he describes as "forming the embankment for the lake," .... "nearly 500 yards in length, with a breadth varying up to 100 yards, and a height of 60 feet above the surface of the lake." Now, with all deference to such an authority, I must be allowed to question the full existence of this large moraine. The hill in question (Low Wood) presents scarcely any sections, being thickly covered with wood; and although it may be seen in parts to be "composed of gravel and subangular or rounded pebbles in a clayey matrix, also enclosing large blocks of porphyry and other rocks,". the sections are only skin-deep; and from the first I had a strong suspicion that the low hill, like so

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* I was unable to take any deeper sounding than 251 feet, though popular opinion gives a greater depth, and the opinion of the country-folk is that the lake is unfathomable.

† Geologist, vol. iv. p. 478.

many others in the country, was probably a rounded boss of rock, with a thin covering of drift or moraine-matter. Supposing, however, the whole mass to be morainic, its presence does not explain the formation of the deep rock-basin, unless we could suppose that this groove, 40 feet beneath the sea-level, ran right on to the sea-coast, and was now wholly filled up with drift, with the exception of the present site of Wastwater, the drift-deposit being more than 250 feet thick near the lake-foot —altogether a supposition highly improbable. Hence I think we may conclude that this lake is not *due* to the presence of a terminal moraine.

In 1865, the late Professor Phillips communicated a paper to the British Association on "Glacial Striation (Wastdale)"*, in which, from the great length of the lower, almost level tracts of ground, and the shortness of the upper snow-slopes in ancient days, he concluded that effective pressure could not be continued through the length of Wastdale. Among other reasons for this, he instanced the fact that under the pressure equivalent to 1000 or 1500 vertical feet of ice, that substance would lose its solidity. He also showed by a study of the relative grinding force of the icy weight under different conditions of depth and inclination, that if such pressure could be communicated, it would not be effective in excavating the lake. It would not tend to make a hollow such as a lake would fill, nor deepen such a hollow if previously placed in its path in Wastdale.

This is strong testimony against the idea of glacial erosion; and if it really were the case that under a "pressure equivalent to 1000 or 1500 vertical feet of ice, that substance would lose its solidity," the theory must, I suppose, be abandoned. But in Arctic and Antarctic regions ice sheets of a much greater thickness than this have been seen, apparently solid throughout, and regelation would soon come into play if crushing *were* partially effected†. The lowering of the melting-point by pressure must also be considered, which, while tending to facilitate regelation, would not be likely to materially affect the solidity of the ice, especially if we may safely assume that the temperature of the bottom layers of ice was well below the freezing-point during the glacial period‡.

Now, I have already stated my belief that at one time the ice coming down the Wastwater valley was fully 1500 feet thick, measured from the present *surface* of the lake. In the longitudinal section, however (Pl. VII. A, fig. 1), I have made the thickness, above the deepest part of the lake, only 1300 feet above the present lake-surface. If we compare the relative thickness of ice and depth of

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* Rept. Brit. Assoc. 1865, Trans. Sect. p. 71.

† See Croll, "On the Cause of the Motion of Glaciers," Phil. Mag. Sept. 1870.

‡ Sir W. Thomson has found that "pressures of 8·1 and 16·8 atmospheres lowered the melting-point of ice by 0·059° and 0·126° C. respectively. These results justify the conclusion of Prof. J. Thomson, according to which an increase of pressure of n atmospheres lowers the melting-point of ice by $0·0074n°$ C." (Ganot's Physics § 306, p. 249: ed. 1872). Since a column of ice 1000 feet thick very nearly equals 29 atmospheres, a pressure of 1000 feet of ice would lower the melting-point ·2146° C., and one of 5000 feet would only lower it 1° C.

water in this case with those of Buttermere and Derwentwater given in the former paper, we find as follows* :—

	Lake.	Ice.
Wastwater	250	1300
Buttermere	90	850
Derwentwater	73	900

that is to say, while the depth of Wastwater is about three times as great as that of Buttermere and Derwentwater, the thickness of ice which may have moved over these spots before the lake-basins were made is considerably more than one third greater in the first case than in the other two. Another point to be considered is the fact that the deepest part of the lake occurs just beyond the spot where a great accession of ice must have joined the main glacier from down the wide double valley in which Over Beck and Nether Beck run, and the line of greatest depth immediately swerves over to the opposite shore, beneath the steep Screes, where the greatest pressure would be exercised (Pl. VII. A, figs. 6 & 7). These facts tend strongly to support the theory of glacial erosion.

If I am right in the supposition that a line of granite extends up the valley beneath the lake, it is possible that the nature of the rock may have facilitated the erosion.

b. *Grasmere and Easdale.*—In Pl. VII. B, fig. 12 is a longitudinal section through Codale and Easdale Tarns, and Grasmere; and the mountains shown in outline are those lying to the north. I think I may safely say I have rather under- than overrated the thickness of the ice which passed over these tarns and lakes; and it will be seen at once how insignificant are the hollows in which these lie, as compared with this thickness. Figs. 13 and 14 are transverse sections along the lines drawn on the map, Pl. VII. C. Prof. Hull considered† Easdale Tarn, together with Stickle and Blea Tarns, to be moraine-dammed. Doubtless he was unaware of the depth of Easdale (71 feet), a depth very considerable for so small an upland lake. There are, indeed, moraines about the foot of the tarn, though the high bank just on the north side of the stream is a great ice-worn mass of rock covered with a coating of moraine-drift upon its western flank. The stream also shows rock in its bed directly after leaving the lake and only some few feet below its level; and I think this tarn is, when the depth is considered, almost as good an example of a rock-basin as possible.

Codale Tarn, more than 600 feet above Easdale, is another good case of such a basin; and ice-scratches may be seen upon its eastern shore, pointing as if certainly made by ice coming straight up out of the rocky hollow. I was unable to ascertain its depth, though it would seem to be but shallow, very likely less than half that of

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* It should be borne in mind that in all the drawings giving the thickness of the ice and the depth of the water on a true scale, a low estimate of the former has always been taken.

† "On the Vestiges of Extinct Glaciers in the Lake-districts of Cumberland and Westmoreland," Edin. New Phil. Journ. ser. 2, vol. xi. p. 31.

Easdale. It may seem strange to some, on the glacial-erosion theory, that Easdale under a moderate thickness of ice should be as deep as Grasmere or Derwentwater under a much greater thickness. But we should always consider the nature of the ground in every case. Thus, in that of Easdale we might have the scooping power exercised just at the foot of a very considerable fall (see fig. 12), while in the case of Grasmere the *main* mass of ice would be moving down a valley of very gentle slope; and it might be that when some obstacle, such as Loughrigg Fell (65), was opposed to its onward path, then the deepest hollow was excavated. Certainly, if we are to admit that the other lake-basins already treated of were formed by glacial erosion, there is no difficulty in including such tarns as Codale and Easdale, and such lakes as Grasmere, under the same head.

c. *Langdale Old Lake.*—It seems highly probable that there formerly existed a long lake in Great Langdale, now represented by a stretch of alluvial land, which is not unfrequently much flooded. Fig. 15, Pl. VII. B, is a section of the head of this valley, where Mickleden and Oxendale unite; and in fig. 14 the form of the valley is again seen near the termination of the lake at Chapel Stile. Mention has already been made of the volume of ice which flowed down the dale, and which, on the theory of glacial erosion, may have been instrumental in the formation of this old lake, since filled up by material brought down from the head and steep sides of the valley.

d. *Various Tarns.*—It is not easy to determine certainly whether a tarn be moraine-dammed or whether it be a true rock-basin, unless its depth is known and the probable thickness of the morainic material. Thus, at first sight, Easdale Tarn might appear to belong to the former group; but when its depth is known, and that depth compared with the height at which rock is seen below the moraine-material, it may be confidently classed with the true rock-basins.

There is every transition from the merest rock-bound pool, with glaciated inner surface, to tarns of considerable size, down beneath the waters of which the ice-scratches may be seen to run, and which are bounded at their lower ends either by a rounded rocky rim, by the same with a thin *covering* of moraine-material, or by undoubted moraines, which extend below the level of the water. So that a tarn may owe its existence to a basin-like hollow formed in the solid rock—to a somewhat similar hollow not wholly surrounded by a rocky rim, but having the open end dammed by morainic or similar matter—and to a combination of these two, in which case a certain depth of water may be retained by a continuous rocky rim, and the remaining depth by a moraine dam. In any part of the district which is much glaciated—or, rather, in which the effects of glaciation are well preserved—there may be seen many examples of tiny ice-worn rock-basins. Just below and south of Nethermost Pike, Hellvellyn (6)*, in Ruthwaite Cove, is Hard Tarn, 150 feet by less than 100 in size it is very shallow, so that one can see the rocky nature of its bed and sides, and mark how the ice-scratches pass beneath the water from one side to the other.

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* See Map in first paper.

In the case of Red Tarn (fig. 18, Pl. VII. B), immediately beneath Helvellyn, scratched rock-surfaces may be seen passing beneath the water at its upper end, while the banks at the lower seem made up of morainic material. This tarn is very shallow and was dry in 1869; so that it is very likely that we have here merely a glaciated hollow in the comb—between Swirral and Striding Edges—converted into a lake by moraine-rubbish deposited at its lower end. Keppelcove Tarn, a little further north, is also moraine-dammed; but whether wholly so or not, it is difficult to say*; at any rate glacial scratches may be seen on the rocky western sides.

Stickle and Angle Tarns (figs. 21 and 20) are probably both rock-basins of a slight depth converted into tarns of a greater depth by moraines at the lower end; and Blea Tarn, between Great and Little Langdale, although now nearly filled up, may originally have been a tolerably deep rock-basin, the mounds at its lower end, which at first sight look like moraines, being rounded rocks with a thin coating of moraine-matter.

In all these cases it is clear, from the glaciated rock-surfaces, that ice has occupied the hollows now filled by the tarns; and it is difficult to admit its scooping power in the case of very small rocky basins and deny it in that of the larger, especially when it is remembered that in many cases part, at any rate, of the depth, is accounted for by the presence of moraines at the lower end.

There are some instances, however, where no glacial markings have been observed at the sides of a tarn, and yet at its lower end there may be what appears like a conspicuous moraine. Of such is Bowscale Tarn, two or three miles north of Blencathra (Saddleback). It is possible that the Hornblende Slate, of which the tarn crags are composed, has lost glacial markings originally impressed upon it; but at the same time the gathering-ground for a glacier is here very small, and it is quite conceivable that the moraine-like mound at the north side of the tarn represents the *débris* accumulated at the foot of a *snow-slope* (fig. 19). The same may be the case in some other instances of apparently moraine-dammed tarns. The objection that is sometimes made to the glacial-erosion theory, when applied to the case of tarns lying in combs, that there could have been no feeding-ground for a glacier, is opposed by the fact that ice-scratches, pointing directly out of the combs and often at the head of the tarns, are frequently met with. The way also in which these scratches occur, conforming in direction to the shape of the comb, show that they must have been produced by small glaciers originating in or occupying the hollow. Such tarns as Burnmoor (31 feet deep†), Blea, Little Langdale, Elterwater (29 feet deep†), and Loughrigg (34 feet deep‡), all lie in the direct paths of the main glaciers, and, since most of them appear to be rock-basins, come under the same head as the lakes before treated of.

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* Both these tarns have been converted into reservoirs, by means of artificial dams and sluices, for the use of the Greenside mine.

† Sounded by my colleague, Mr. Hebert.

‡ Sounded by my colleague, Mr. De Rance.

e. *Windermere and Coniston.*—In the case of these lakes I am inclined to believe, from the evidence brought forward on page 154, that the ice-sheet supplied from the various dales within a circular northern sweep from Wetherlam to Wansfell Pike, and crossing the whole area of ground directly between these heights (fig. 22, Pl. VII. D), passed southwards, and, *becoming concentrated* in the already existing north-and-south valleys, was effective in forming the long slight grooves in which the lakes of Windermere, Esthwaite, and Coniston now lie*.

Windermere is divided into two basins by Belle Isle and other islands: in the upper reach, the bottom is beneath the sea-level for a distance of 3 miles; and in the lower the bottom just reaches the sea-level†. Fig. 25 is a *transverse* section through the deepest part of Windermere, near Wray Castle; and fig. 26 is another, crossing some 2½ miles above the foot of the lake. The transverse section in fig. 23 crosses about ¾ of a mile north of Belle Isle.

It is not quite clear why the islands at the centre of Windermere should have been spared by denudation to divide the present lake into two basins, since, so far as I can learn, there is nothing in the superior hardness of the rocks at that spot to explain it. It is the case, however, that just in that neighbourhood the valley widens somewhat; and thus perhaps the ice was enabled to spread laterally; while we may reasonably suppose that the islands represent only the degraded stumps of rocky hills which stood well above the valley-bottom in preglacial times.

IV. INFLUENCE OF GEOLOGICAL STRUCTURE ON LAKE-ORIGIN.

I do not think any case can be pointed to in which a lake-hollow has been directly formed at a certain spot because of the presence of particular geological features at that spot. As a general rule, the lakes in this district lie with their longer axis in a direction across that of the strike of the strata, and this because the valleys in which they have been formed had that direction previously. That faults pass through some of the lakes is but little to the point, as it was probably the existence of such faults, bringing together beds of different degrees of hardness, that gave the initial directions to some of the valleys. Moreover most of the largest lakes do not apparently lie along lines of fault, and even those with such long straight courses as Windermere and Coniston do not, according to Mr. Aveline, run wholly along any large fault; for while at the

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* In the figures I have purposely drawn the upper surface of the ice level; but of course this would not always be so in nature.

† The soundings used in this section and in that of Coniston were taken many years ago by Mr. P. C. Crosthwaite. The greatest depth of Windermere, 234 feet, has been found by Mr. De Rance just opposite Wray Castle, and the greatest depth of Coniston, 174 feet, by Messrs. Aveline and Camerod, who have taken the depths of this lake throughout. Mr. Cameron has sounded Esthwaite Water and found its deepest part to be only 51 feet.

head of each the various beds of the Upper Silurian are shifted, and markedly so in the case of Coniston, further down the lakes the strata would appear to cross unbroken.

V. Summary.

1. During the period of maximum glaciation, the various glaciers of this southern part of the district, as of the northern, were more or less confluent, and most of the lower elevations were buried under a continuous sheet of ice, which often moved diagonally across the lower parts of ridges separating valley from valley.

2. The occurrence of some glacial scratches crossing water-shedding lines at high elevations, in a general east and west direction, and frequently in passes or cols, seems to point, perhaps somewhat doubtfully, to the agency of floating ice, and to support the supposition that the submergence reached to more than 2000 feet*, and may have extended to but little short of 2500 feet.

3. The existing moraines are the products of the second land-glaciation; the glaciers of this period seem never to have become confluent, as in the former, but occupied the heads of all the principal valleys.

4. Several of the larger lakes, such as Wastwater and Windermere, are rock-basins running down beneath the present sea-level.

5. These rock-basins, however, are but shallow grooves at the bottom of the valleys in which they occur; and their depth is small as compared with the thickness of the ice which moved over these spots. Hence it seems most probable that the theory of glacial erosion is the true one, and the points of evidence brought forward in the case of Wastwater are strongly confirmatory.

6. Mountain-tarns appear to be due, sometimes wholly to glacial erosion, sometimes to this combined with a moraine dam, and occasionally to the pounding back of water by moraines alone, or moraine-like mounds, at the foot of snow-slopes.

EXPLANATION OF PLATE VII.

A. Horizontal sections to illustrate the form of the Wastwater valley, the depth of the lake, the height of the mountains, and the thickness of the ice, together with a plan of Wastwater,—depths being given in feet. All on a true scale of 1 inch to 1 mile.

Fig. 1. Longitudinal section through Wastwater, with outlines of the mountains occurring on the north side of the valley.
2. Transverse section through Wastdale Head, between Kirk Fell and Scafell Pikes.
3. Section from Pillar Mountain to Scafell, through the junction of Mosedale and the head of Wastdale.
4. Transverse section from Yewbarrow to the N.E. end of the Screes Mountain.
5. Transverse section from the mouth of Over Beck to the N.E. end of the Screes Mountain.

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* See "Summary" in "Glaciation of the Northern Part of the Lake-District," Quart. Journ. Geol. Soc. vol. xxix. p. 440.

Fig. 6. Transverse section along the line marked fig. 6 in the plan, fig. 11.
7. Transverse section from Middle Fell to Illgill Head.
8. Transverse section along the line marked fig. 8 in the plan, fig. 11.
9. Transverse section from Buckbarrow to the Screes.
10. Transverse section along the line marked fig. 10 in the plan, fig. 11.
11. Plan of Wastwater, with depths given in feet, and lines along which the longitudinal and transverse sections run.

B. Horizontal sections to illustrate the forms of Langdale, Easdale, and other valleys, the depths of lakes and tarns, the heights of the mountains, and the thickness of the ice; together with plans of Grasmere and Easdale Tarn. All on a true scale of 1 inch to 1 mile.

Fig. 12. Longitudinal section from Sergeant Man to Loughrigg Fell, through Codale Tarn, Easdale Tarn, and Grasmere, with the outlines of mountains on the north.
13. Transverse section through Langdale and the heads of Easdale and Far Easdale.
14. Section across the lower ends of Great Langdale and Grasmere from Lingmoor to Nab Scar.
15. Section across the head of Great Langdale just below the junction of Oxendale and Mickleden, from Pike of Blisco to Harrison Stickle.
16. Plan of Easdale Tarn, with depths given in feet.
17. Plan of Grasmere, with depths given in feet.
18. Section from Helvellyn summit through Red Tarn.
19. Section through Bowscale Tarn; the dotted line may represent a former snow-slope.
20. Section through Hanging Knotts and Angle Tarn.
21. Section from Pavey Ark through Stickle Tarn.

C. Map of a portion of the southern part of the Lake-district, a continuation southwards of map given in former paper (Quart. Journ. Geol. Soc. May, 1874). Scale ½ inch to 1 mile.

D. Horizontal sections to illustrate the depths of Coniston Water and Windermere, the form of the ground along various lines, and the thickness of the ice. All on a true scale of 1 inch to 1 mile.

Fig. 22. Section from Wetherlam to Wansfell Pike.
23. Section from Coniston Old Man to a point east of Windermere Railway-station.
24. Longitudinal section through Codale and Easdale Tarns, Grasmere, and Windermere.
25. Transverse section through Windermere, near Wray Castle.
26. Transverse section through Windermere, 2½ miles above the lake-foot.

N.B. In all cases the thickness of the ice shown in these horizontal sections is probably below the *maximum*.

Discussion.

Mr. Drew said that it was quite unnecessary to praise the paper, but remarked that in the section 1000 feet of ice was shown passing with a very slight slope over the present very uneven ground, and that he did not think that ice sloping at so small an angle could produce such inequalities of surface. He thought that the production of hollows must take place only at the termination of the glaciers.

Prof. Ramsay said that his theory of the formation of rock-basins seemed to be gradually gaining ground. It is not impossible that rock-barriers sloping up in the middle of valleys may have originated in the difference of hardness of the material eroded by glaciers. He did not think that basins were necessarily formed only at the terminations of glaciers. The meeting of two rivers produces a great turmoil in the waters, increasing their erosive powers, and producing a pool. This may be the case also with the meeting of two glaciers, although from the nature of the material it is not directly recognizable; but the pressure and grinding-power would be greatest there.

The Rev. T. G. **Bonney** agreed with Mr. Drew that Mr. Ward's observations, though very valuable, could not necessarily be applied to explain more than the region described. Though he admitted Mr. Ward had established his point, on the whole, for the English lakes, he did not think that the larger Swiss and Italian lakes could be so explained. He had carefully examined both districts: in the former the configuration of the ground was such as generally favoured glacier-erosion; in the latter the evidence went quite the other way.

Mr. **Koch** remarked that one of the most interesting points brought forward by the author was that relating to the comparative thickness of the ice and the depth of the excavations. He thought that carefully pursued researches in this direction would probably lead to valuable results.

Mr. **Evans** thought that there was an inclination on the part of some geologists to undervalue the grinding-power of glaciers; but the muddy water from the foot of a glacier shows that this power is considerable. When the passage for the ice is contracted, as at the incoming of a glacier from a lateral valley, there must be an increase of the grinding-power.

Mr. **Ward** replied to Mr. Drew, that the horizontal or but gently sloping *upper* surface of the ice, as shown in the sections, was purely diagrammatic; in nature this surface may in many cases have presented great irregularities. While believing that many tarns lying in combs have been excavated by glaciers often generated on the comb-slopes, he maintained that the larger lakes, such as Wastwater, with its greatest depth beneath the sea-level, could not have been formed merely at the end or snout of a glacier, but were due to the passage of a thick glacier-sheet through the valley-length over the present lake-sites. Whether the paper did or did not advance Prof. Ramsay's theory in general, if it had proved the glacial origin of the Cumbrian lakes its *purpose* had been effected.

PAPE

B. GRASMERE, EASDALE &c.

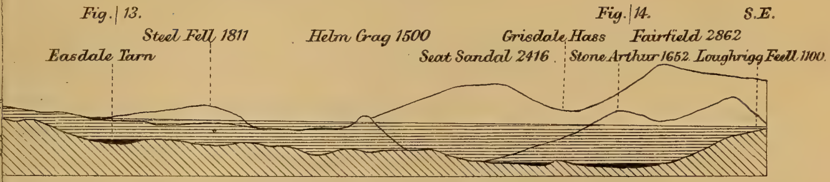

Fig. 12.

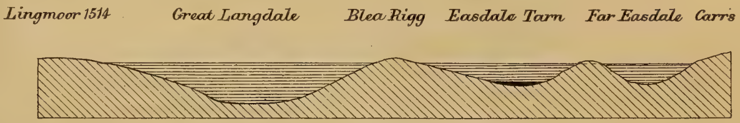

Fig. 13.

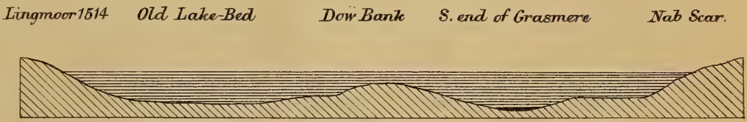

Fig. 14.

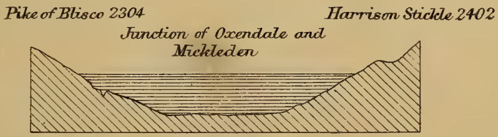

Fig. 15.

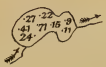

Fig. 16. *Easdale Tarn*

Surface of Water 915 feet.

Fig. 17.

Surface of Water 208 feet

Depths given in feet.

Windermere

near Wray Castle

Fig. 25.

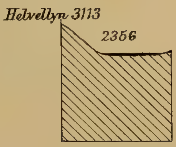

Fig. 18. *Red Tarn*

Fig. 20. *Angle Tarn.*

Windermere

2½ miles above foot.

Fig. 26.

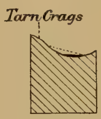

Fig. 19. *Bowscale Tarn*

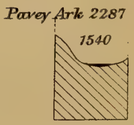

Fig. 21. *Stickle Tarn*

The slanting lines indicating the sections of rock have no relation to the dip of the beds.

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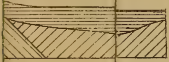
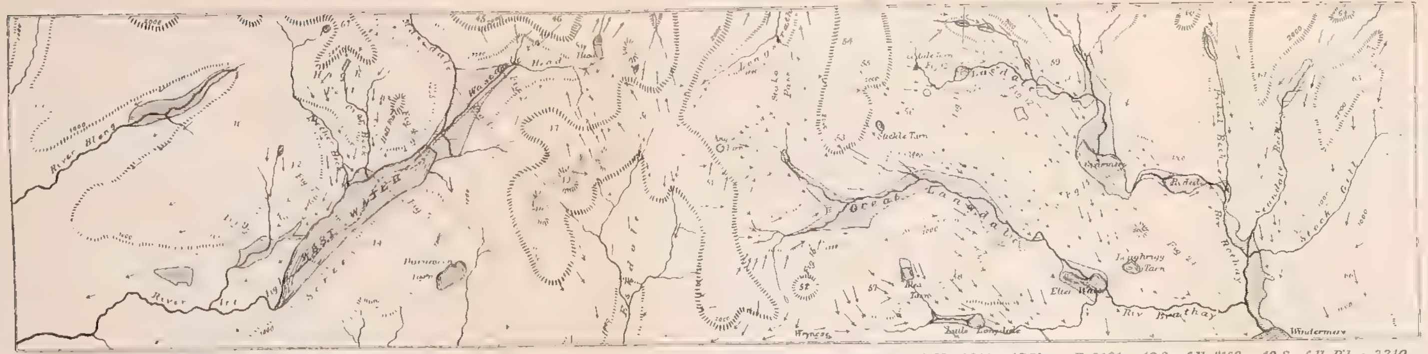


Easdale Ta

ke

PLANS AND SECTIONS TO ILLUSTRATE PAPER ON "THE ORIGIN OF SOME OF THE LAKE BASINS OF CUMBERLAND AND WESTMORELAND".

C. MAP OF A PORTION OF THE SOUTHERN PART OF THE LAKE DISTRICT.



40, Scatallan 2266. 41 Buckbarrow 1250. 42 Middle Fell 1908. 43, Yewbarrow 2058. 44 Illgill Head 1978. 45, Kirk Fell 2630. – 46, Great Gable 2949. – 47, Lingmell 2104. – 48, Scafell 3162. – 49, Scafell Pikes 3210. – 50, Great End 2984. – 51, Bow Fell 2960. 52, Pike of Blisco 2304. 53, Langdale Pikes Pike of Stickle 2323. Harrison Stickle 2401. – 54, High White Stones 2500. – 55, Sergeant Man 2414. 56 Blea Rigg 1776. 57, Blake Rigg 1760. – 58, Lingmoor Fell 1514. – 59, Helm Crag 1299. – 60, Great Rigg 2513. – 61, Near Swine Crag 2155. – 62, Middle Dod 2106. – 63, Red Screes 2541. – 64, Little Hart Crag 2091. – 65, Loughrigg Fell 1101. – 66, Wansfell Pike 1581. – 67, Red Pike 2706. The fine straight lines are those along which the Sections in Series A, B and D are drawn. The dotted line through Wast Water = greatest depth.

Contours ▤ — 1000 feet. ▥ — 2000 feet. ▥ — 3000 feet. ▨ Filled up Lakes. The points of the Arrows indicate the Ice marks.

A. WASTWATER.

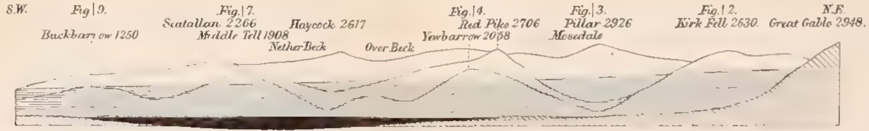


Fig 1

B. GRASMERE, EASDALE &c.

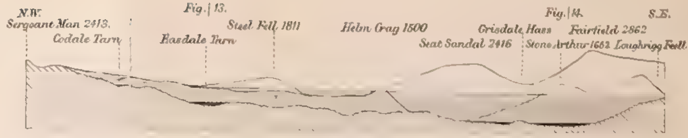


Fig. 12

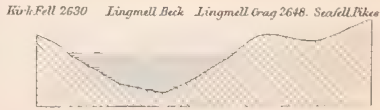


Fig 2

Fig. 3.

Fig 13

Fig 4

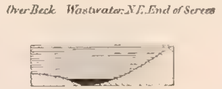


Fig. 5.

Fig 6

Fig. 7

Fig. 8

Fig. 14.

Fig 9

Fig. 10

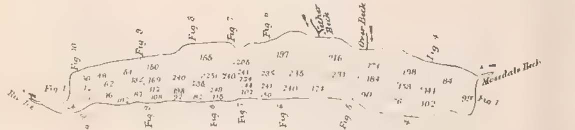


Fig. 11. Wastwater.

Surface of Water 204 feet
Depth given in feet.

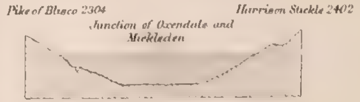


Fig 15

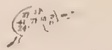


Fig. 16. Easdale Tarn

Surface of Water 916 feet

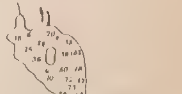


Fig 17

Surface of Water 208 feet

Depths given in feet

D. WINDERMERE &c.

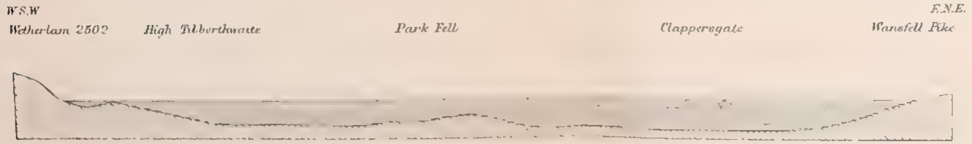


Fig 22

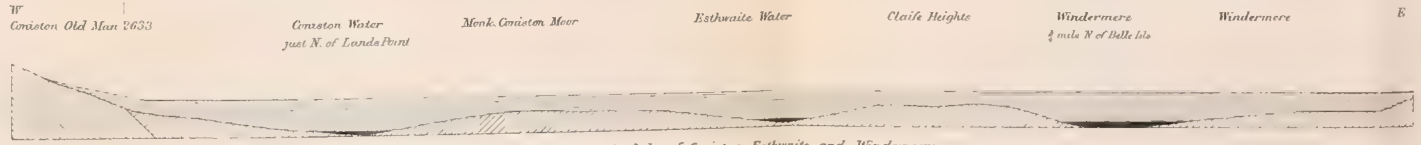


Fig. 23. Transverse section through the lakes of Coniston, Esthwaite and Windermere.

Fig. 25.

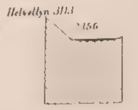


Fig. 18. Red Tarn

Fig. 20. Angle Tarn

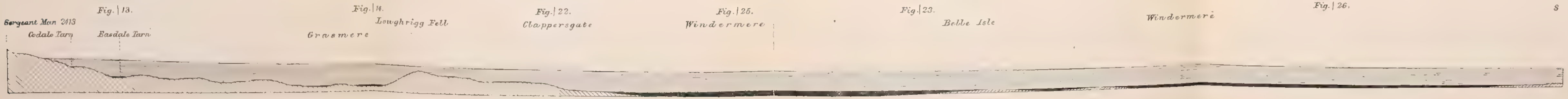


Fig. 24. Longitudinal section through Codale and Easdale Tarns, Grasmere and Windermere.

Fig 26.

Fig 19. Bowscale Tarn

Fig. 21. Stickle Tarn

Note. The horizontal upper surface of the ice is diagrammatic only

▧ Rock Section (L. Silurian.) ▨ Rock Section (U. Silurian.) ▭ Glacier Ice. ▬ Lake

The marks thus "Fig. | 13." show where the transverse Sections cross the longitudinal.

Scale, 1 inch to 1 mile, both vertical and horizontal

Note. The slanting lines indicating the sections of rock have no relation to the dip of the heads.

Mintern Bros lith.

13. *On the* SUCCESSION *of the* ANCIENT ROCKS *in the vicinity of* ST. DAVID'S, PEMBROKESHIRE, *with special reference to those of the* ARENIG *and* LLANDEILO GROUPS, *and their* FOSSIL CONTENTS. By HENRY HICKS, Esq., F.G.S. (Read December 2, 1874.)

[PLATES VIII.-XI.]

INTRODUCTION.

IN my last paper, communicated to the Geological Society in December 1872, the order of the succession of the strata in the vicinity of St. David's was carefully tabulated to the top of the Tremadoc group; and it was there shown that the succession was a perfectly continuous one from the base of the Cambrian series to the top of the Tremadoc group, and that the only break or unconformity recognized was at the base of the Cambrian, where it rested on the pre-Cambrian ridge. In the accompanying map and sections (Pl. VIII.) the following order of the rocks is shown. Directly under the city of St. David's, or, rather, under its eastern portion, are some massive beds of quartzy conglomerates, very compact in structure, but alternating with dark-green shales, with a strike from N.W. to S.E. These have a thickness as we follow them directly eastward from this spot of about 4000 feet; and they run, with a varying thickness not exceeding this, for about five miles in a N.E. direction from St. David's, but are then cut off by a fault. They also extend in a line to the S.W., reaching the coast of St. Bride's Bay, on the east side of Porth-lisky Harbour, but are considerably reduced in thickness at this part by a fault running in a N.E. direction. The ridge formed by these rocks underlies the whole of the remaining strata of the district, being the axis on which the Cambrian and other rocks are supported. This ridge is marked in the Geological-Survey maps as a mass of intrusive syenite; and in some places, especially near the centre, it may be said, from its very compact nature, to assume almost that character; but when the mass is more carefully examined, it is evident that the whole is composed of bedded rock, partly metamorphosed.

The difference in the thickness of the ridge in our map in places from that shown on the Survey maps is accounted for by our having excluded some strata along the edge which belong to the overlying Cambrian series, and which rest unconformably on the ridge. The bedding of the strata composing the ridge may be distinctly seen in the hill to the N.E. of the Cathedral, also on the west side of the valley beyond the mill between St. David's and Porth-clais, and on the east side of Porth-lisky Harbour. The beds forming the Harlech or Longmynd group, consisting of green shales, conglomerates, and purple, red, and green sandstones and slates, are seen on both sides of the ridge; they rest unconformably on the edges of the beds of the axis; and there are indications that they once extended over it, but that they have been subsequently denuded off. On the west side, as may be seen in Section I. (Pl. VIII. fig. 2), they form two distinct folds, which terminate on the west coast in a section comprising more than 4000 feet of strata in natural order of succession. Over 3000 feet of the beds in this section have yielded fossils; and good specimens of *Lingulella primæva* are found in the red beds near the conglomerates, at Castell in Ramsey Sound. Many, indeed most, of the beds between Ramsey Sound and St. David's are considerably altered; but there are no intrusive masses amongst them of any importance; the great mass on the east of Ramsey Sound, coloured as greenstone in the Survey maps, is nothing more than bedded Cambrian rock altered. On the east side of the axis the same order of succession occurs as on the west, but the beds are less altered. In the line of the section (fig. 2) it will be seen that they do not repeat themselves as on the west side; but further eastward they again fold over several times. About 700 feet of the beds in this part of the section have been removed by a fault along the line of the bedding; otherwise it is similar to the one in Ramsey Sound. The chief places for fossils on the east side are the red beds faulted against the ridge at Porth-clais, and the same beds on the coast near Nun's Chapel and at Caerfai, also the grey flags in the second point west of Porth-clais, where *Plutonia Sedgwickii*, *Conocoryphe Lyellii*, *Paradoxides Harknessi*, and other fossils occur.

The beds of the Menevian group, the next in order of succession, are best seen on the coast east and west of Porth-y-rhaw. A little to the west side of that creek they may be seen resting conformably on the red beds of the Longmynd group, also at Pen-pleidiau, and in Solva Harbour. In Whitesand Bay, on the west coast, they are also found resting conformably on beds of the underlying group.

The thickness of the Menevian group is about 600 feet; and nearly all the beds are richly fossiliferous wherever found. Lithologically the Menevian group differs considerably from the Longmynd group; but palæontologically the connexion between them is so strong that it is impossible to separate them by any stronger line of division than as subgroups in a great subdivision. It was on this account that as far back as the year 1867* I proposed that the Menevian and Longmynd groups should be combined together as Lower Cambrian, and that the divisional line should be above instead of below the Menevian, as it had up to that time been placed.

The next group in order of succession, the Lingula-flag group, is seen resting conformably on the upper beds of the Menevian group, a little to the east of Porth-y-rhaw, and again at Solva Harbour, and near Caerfegga; also on the west coast in Whitesand Bay. The group consists of alternating beds of sandstones and shales, with occasional thick bands of black slates, and it is about 2000 feet thick. It is considerably thinner than in North Wales; and very few fossils have yet been found in it near St. David's. At White-

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* Table of strata, exhibited in the Arts and Science Department of the National Eistedfodd at Carmarthen, 1867, and Brit. Assoc. Report, 1868.

sand Bay, however, and at Ramsey Island, the characteristic *Lingulella Davisii* is to be found in great abundance. At St. David's the series is made up of very even deposits from the beginning to the close, and no sudden change takes place anywhere in the character of the sediment. In North Wales, before the close of the epoch, there is evidence that a depression of the sea-bottom rather suddenly took place; and with this depression a fine silt was thrown down, in which a fauna unknown to South Wales occurs. These are the deposits now known as the *Olenus*-shales, which are found in North Wales and in the neighbourhood of Malvern. For the same reasons we find that the Tremadoc group, which immediately succeeds the Lingula-flags, is also rather different lithologically in North and South Wales. The depression in the St.-David's area continued to go on very gradually even in the Tremadoc epoch; hence the character of the deposit is on the whole that of shallower water than that in North Wales, and the fauna varies accordingly, as may be noticed in the unusual prevalence and size of the Lamellibranchiata and the Brachiopoda found in these beds at St. David's. Some parts of the series, however, are very similar in character, and indicate the presence of like conditions in both districts, especially in the earlier stages of the formation.

The beds of the Tremadoc group can be seen on the east side of the anticlinal, resting conformably on the Lingula-flags about Tremanhire, and beyond Caerfegga; but as there are only a few exposures of the strata in that neighbourhood, in consequence of the ground being covered over by drift, the further succession will have to be illustrated chiefly by reference to the sections on the north side of the axis. In the north end of Ramsey Island, or rather at the north-east point (fig. 3), the Tremadoc group is seen in an excellent coast-section with the lower beds resting quite conformably on the Lingula-flags, and the change from the one group to the other is very gradual. The group consists for the most part of dark earthy flags and flaggy sandstones, with some iron-stained slates at the top, and it is rather less than 1000 feet in thickness. The beds here are exceedingly rich in fossils, and they have yielded many important new forms. At Trwyn-hwrddyn, in Whitesand Bay, the lower beds of the group are also seen resting conformably on the Lingula-flags (fig. 4), but the upper portion is cut off by an east and west fault. A little further inland from this spot, however, the fault has crossed the series, and the group is again seen in its proper thickness *. Near Lanveran the beds are well exposed, and the characteristic fossils are found in them. From here they take a more easterly strike; and they may be followed for several miles in that direction.

The next succeeding groups are the Arenig and Llandeilo; and these I shall have to refer to more in detail, as they have not

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* The fault of which this is a branch, as will be seen by reference to the Map and Section IV. (Pl. VIII. figs. 1 & 5), has somewhat interfered with the succession along the north edge of the anticlinal by cutting off the whole of the Menevian group and part of the Lingula-flags.

hitherto been described in my papers to the Society, and some of the facts have been but recently made out*.

Arenig and Llandeilo Groups.

History of the Names.—In a paper read by Professor Sedgwick before the Geological Society on the 25th Feb., 1852, he describes the "Arenig slates and porphyries" as forming a distinct and well-marked subgroup in his previously named "Ffestiniog group," and as resting conformably on the underlying group, to which he had given the name of "Tremadoc slates." This is the first description of the series under the above heading that I have been able to find; but in papers read by him before the Society on Nov. 29th, 1843, and on Dec. 16th, 1846, the series is frequently referred to, and described as "a great group of roofing-slate, and contemporaneous porphyry," the former passing into grits, flags, &c., and comprised in his Snowdonian group. The series is also stated to occur in the chains of Arenig, Aran Mowddwy, and Cader Idris, and in the Ffestiniog mountains; and sections are given in which its position is clearly marked. In his 'Synopsis of the Classification of the British Palæozoic Rocks,' published in 1852–55, he adopts the same arrangement as in his paper in 1852. Since that time but little has been done to elucidate the position of the group in North Wales, and the name has almost been allowed to lapse. Mr. Salter's researches in portions of the series, however, have been of very great importance, and will be fully referred to when these parts are described.

The Llandeilo group was named by Sir R. Murchison about the year 1834, and was intended by him to indicate a series of calcareous flagstones, schists, and sandstones exposed in the neighbourhood of Llandeilo in Carmarthenshire, and about Builth in Breconshire. The exact position of the group in the succession, however, was a doubtful point for many years afterwards, and it was not made at all clear until the districts were examined by the Geological Survey in 1842, and then chiefly through the labours of Prof. Ramsay. The description given of it at this time (1842), as developed at Llandeilo and Builth, was a series of schists, flags, and limestones, with interstratified trap at the base, the whole underlying conformably the Caradoc or Bala group. As here defined, it does not include properly any beds of the age of the great series previously discovered by Prof. Sedgwick in North Wales, and afterwards described by him in the above-mentioned papers as "Arenig slates and

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* Memoirs published on the rocks of St. David's in addition to those mentioned in the Quart. Journ. Geol. Soc. Nov. 1871:—

Hicks, Trans. Liverpool Geol. Soc. 1869.

Harkness and Hicks, Quart. Journ. Geol. Soc. Nov. 1871.

Hicks, Geol. Mag. Dec. 1869; Quart. Journ. Geol. Soc. May 1872; Trans. Brit. Assoc. 1872.

Hopkinson, Trans. Brit. Assoc. 1872.

Hicks, Proc. Geologists' Assoc. vol. iii. 1873; Quart. Journ. Geol. Soc. Feb. 1873; Trans. Brit. Assoc. 1873.

porphyries;" nor could it have been intended at the time that it should comprise more than was really to be found in the typical district. Unfortunately, however, from a mistaken idea of the relative age of the two series, the name Llandeilo was gradually made to include the whole of Prof. Sedgwick's group; and therefore a meaning was given to the name far greater than could have been at first intended, or than it had the slightest claim to—as may be seen by referring to 'Siluria,' 2nd edition, 1859, and to Prof. Ramsay's 'Memoir on North Wales,' 1866, where it is mentioned that "since 1848 the Geological Survey have been in the habit of considering the slates close below and above the Arans and Arenigs &c. of North Wales as equivalent to the Llandeilo flags of Builth and Shelve." The group, as it occurs in the typical Llandeilo district, is sufficiently important to occupy a good position in the classification; and more should not be asked for it. The relative position of the two groups is that of two distinct but conformable series, intervening between the Tremadoc group on the one hand and the Bala group on the other; and the proportion of the series at St. David's now given to each group is that which, on comparison with the sections in the typical districts, each seems to have a real claim to. If, therefore, the arrangement should appear to differ in some of its details from that previously adopted in describing these rocks, I must ask for it the recognition due to more recent observations, to a careful comparison with sections in most other Welsh areas, and to a desire to adopt the lines only for the subdivisions which nature seems to indicate by combined palæontological and lithological evidence.

Arenig Group.

The rocks in the neighbourhood of St. David's, which I propose to group together under Prof. Sedgwick's name, "Arenig," consist for the most part of black slates. They lie conformably on the Tremadoc group along the north side of the anticlinal, and they may be traced in an unbroken course for from six to seven miles, the strike of the beds varying only as they curve with the general axis. They also occur at Ramsey Island, faulted against beds of the Harlech group, having been brought down along with some beds of the Tremadoc group and Lingula-flags. The chief fault which caused this change in their position is the one indicated by the line of Ramsey Sound; but it was doubtless assisted by the others now visible in the island. The rocks indicate the prevalence of a deep sea when they were deposited, and show that the depression of the sea-bottom, which had been gradually taking taking place during the deposition of previous groups, had now become much more decided. The depression also seems to have culminated early in the Arenig period, and then to have continued much in that state during the remainder of the epoch. The group contains altogether near 4000 feet of these deep-sea deposits; and, considering the very slow rate at which such deposits must have been accumulated, it is evident that it must span over an enormous period, and, in consequence, that it must contain within it evidences of the presence of many separate and distinct faunas. I propose therefore, for convenience of reference, and for the purpose of comparison with the series in other districts in which the succession may not be so clear, to divide the group, by means chiefly of the fossil zones, into three subgroups, under the names Lower, Middle, and Upper Arenig.

The *Lower Arenig* series is made up of very fine black slates and shales, with a thickness of about 1000 feet, and with the beds generally at a very high angle. In the north end of Ramsey Island, as shown in Section II. (fig. 3), they are seen resting conformably on the Tremadoc group, with a nearly vertical dip, and with a strike from N.N.E. to S.S.W.; but the upper portion of the series is cut off by a fault which brings them against Lingula-flags dipping in the opposite direction. In the middle portion of the island they occur in greater thickness; but the succession there is considerably interfered with by faults, and the order of the beds can only be made out by the fossil evidence.

In Section III. (fig. 4), which is taken along the north coast of Whitesand Bay, the chief portion of the series may be seen faulted against the lower beds of the Tremadoc group, the intervening beds having been cut off by an east and west fault. A little inland, however, from this spot the fault has crossed the series, and also the underlying groups; and the succession is then seen in perfectly natural order.

In this section the strike of the beds is E.N.E. and W.S.W., with a vertical dip; and this strike is maintained for about three miles, or until we reach the position of Section IV. (fig. 5), when the strike varies to a more nearly east and west course. A line taken along the south side of the greenstone masses called Carn-lwyd, Pen-berry, and Waun-y-beddau will indicate the line of junction of the Arenig group with the Tremadoc group along that strike; and the upper edge of the felspathic trap to the south of Cwm-wdig, the junction further east. The fossils of this subgroup have been chiefly collected in the cliffs at Whitesand Bay, and near to the fault at Road-uchaf in Ramsey Island. The species discovered before the year 1866 were mentioned in the Report by Mr. Salter and myself to the British Association in that year, in which the beds were first described under the name of the Arenig group, and their relation to the other groups at Whitesand Bay and Ramsey Island first pointed out.

In the summer of 1872, however, a most valuable addition was made to the fauna by the discovery at Ramsey Island, through the joint labours of Mr. Homfray of Portmadoc, Mr. Lightbody of Ludlow, Mr. J. Hopkinson, Mr. Kirshaw of Warwick, and myself, of about twenty-two species of Graptolites, which Mr. Hopkinson pronounced to be for the most part new to this country, several of them being entirely new species. Since then many of these species have been found by Mr. Hopkinson and myself in the cliffs of the first creek to the north of Trwyn-hwrddyn in Whitesand Bay; and several new forms have again been added by us to the list, which now includes in all about forty-eight species of Graptolites.

The other fossils found in this series comprise *Asaphus Homfrayi*, *Ogygia scutatrix*, *Trinucleus Sedgwickii*, *Conularia Homfrayi*, *Theca* sp., *Lingula petalon*, and *Orthis remota*. This subgroup is strongly characterized by its rich fauna of dendroid Graptolites, the deep-sea conditions prevalent at the time being doubtless favourable to their growth and development, as there is no evidence of their existence in any previous faunas in the succession here.

The *Middle Arenig* is made up of a series of slates and flags, with narrow bands of sandstones intercalated; and it has a thickness of about 1500 feet. The beds rest conformably on the Lower Arenig; and they can only be distinguished from the latter by having on the whole a more flaggy appearance. They are best exposed at Whitesand Bay, and may be said to begin at the point which separates the creek north of Trwyn-hwrddyn from that in which the slate-quarry occurs. They also extend into the creek called Porth Melgan, directly south of St. David's Head; and they reach across that promontory to the north coast. In the bay on the north coast, the extremity of which is marked Porth-y-dwfr, they are lost for some distance; and we do not meet them again in their proper thickness until we reach the coast west of Section III., beyond a place called Porth-y-rhaw, and where the Upper Arenig beds appear on the coast. Along their course several masses of a rough-grained greenstone may be traced running nearly in the line of bedding. A few fossils were discovered in this series as far back as the year 1860, by Mr. Gibbs of the Geological Survey; and the well-known *Trinucleus Gibbsii* was first discovered by him in these beds at Whitesand Bay. Since then, however, I have been able to make a very considerable addition to the fauna; and though most of these fossils have already been described by the late Mr. Salter, there are yet several new species to be added. The most characteristic fossils in this series, and the most plentiful, are the Trilobites *Ogygia bullina*, *Ogygia peltata*, *Trinucleus Gibbsii*, *Æglina grandis*, and *Ampyx Salteri*. There are also a few Graptolites; but most of these occur in the lower beds only, the middle and upper beds indicating apparently conditions more favourable to Trilobites &c.

The rocks composing the *Upper Arenig* resemble more those of the Lower Arenig than the Middle, being like them very fine-grained dark slates or shales. They have a thickness of nearly 1500 feet, and are well exposed along the north coast, resting on the Middle Arenig, and underlying the Lower Llandeilo.

In beds of this series, at Llanrian, Prof. Hughes of Cambridge, several years ago, found a species of *Illænus*, which I propose now to call *Illænus Hughesii*; the same species, along with a few other fossils, were discovered by me also in a quarry under Llanvirn, near Aber-eiddy, in 1865.

The beds of this series, however, were not thoroughly examined until last summer; nor were the fossils previously discovered sufficiently important to mark it as a distinct subgroup. Last August I was fortunate enough to find, again in the Llanvirn quarry, which is near the centre of the series, a most interesting and important group of fossils, distinct from any previously discovered in any part of the Arenig group at St. David's. Most of the species are new; and amongst the Trilobites is one genus (*Placoparia*) previously unknown in Britain, and found only in France, Spain, and Bohemia. The fauna is, on the whole, very rich in Trilobites; and several genera appear here for the first time in the succession, as *Illænus*, *Illænopsis*, *Barrandea*, *Phacops*, and *Placoparia*; but along with them also we find the genera *Calymene*, *Trinucleus*, and *Æglina*, which had already appeared in the earlier series. The fauna also contains many species of Graptolites, chiefly of the genera *Diplograptus* and *Didymograptus*; and there are also unusually large Cephalopods, Gasteropods, Brachiopods, and Lamellibranchs. The list, which is a very complete one for so early a series, will be found in the Table accompanying this paper; and I have added descriptions of all the new forms, except the Graptolites, which will be described by Messrs. Hopkinson and Lapworth in their paper. The fauna is very like that found in the Angers slate in France, and in M. Barrande's Etage D. 1, in Bohemia, the almost total absence of which in England hitherto has been frequently noticed; and it now enables us readily to recognize the position of those beds in relation to the general succession in this country.

At the south end of Ramsey Island some beds of the Upper Arenig are seen in the form of black shales, between masses of felspathic quartz-porphyry, and faulted against beds of the Harlech group. In these shales at Porth-hayog, in the summer of 1873, Prof. Ramsay, Mr. Etheridge, Mr. Homfray, and myself found several species of Graptolites, also *Calymene parvifrons*, a new *Trinucleus*, and some Brachiopods. These fossils indicate a position for the beds intermediate between the Llanvirn quarry and the Lower Llandeilo.

In the foregoing description of the series which collectively form the Arenig group, I have shown that the sequence of the rocks at St. David's is very perfect, and that there is no evidence of any great physical change from the beginning to the close of the epoch. The lower and upper portions of the series are very homogeneous sediments; but the middle is rather more varied in character, and yet not sufficiently so to indicate any great or sudden change at the time it was deposited. There are three distinct faunas in the group; and only a few species pass from the one to the other. They are closely allied, however, by their general facies; and the group is undoubtedly, both palæontologically and lithologically, one of the most characteristic and important in the early deposits. The succession observed at St. David's is more perfect, and the thickness of the series greater than is found in any other British area; but the group occurs, with nearly the same general succession, also in Carnarvonshire and Shropshire.

In my paper on the Tremadoc rocks of St. David's, read Dec. 1872, I expressed the opinion, on palæontological grounds, that the Lower Arenig beds at St. David's were represented in North Wales by the Upper Tremadoc rocks. The examination of several sections in Carnarvonshire during last summer, under the guidance of Prof. Ramsay and Mr. Homfray, further confirmed my opinion; and I now feel convinced that the Upper Tremadoc beds should be classed with the Arenig group.

The Lower and Upper Tremadoc rocks are quite distinct, and very unlike palæontologically—the fauna of the former, like that of the Tremadoc group at St. David's, being closely allied to that in the Lingula-flags, and that in the latter to the Arenig group. In the Arenig district proper the lower black beds of Prof. Sedgwick's Arenig group are undoubtedly, in regard to their position and their fossils, identical with the Upper Tremadoc as exhibited further west; but there is a slight lithological difference observable, and this probably has prevented their being correlated hitherto.

The sections at Portmadoc, in the Ffestiniog mountains, and to the west of the Arenig mountains, show in each case the following order of the strata:—1. Black shales (Lingula-flags), with *Olenus* &c. 2. Iron-stained slates and flags (Lower Tremadoc), with *Niobe*, *Psilocephalus*, *Neseuretus*, *Conocoryphe*, &c. 3. Dark slates (Garth beds), with *Asaphus Homfrayi*, *Ogygia scutatrix*, *Angelina*, *Conularia*, &c., and, in the Arenig district, some dendroid Graptolites. 4. A thick grit-bed with no fossils. 5. Dark fine-grained slates (Ty-Obry beds), with *Æglina*, *Asaphus*, *Calymene*, *Trinucleus*, *Dionide*, *Dendrograptus*, &c. 6. Ash and tuff beds, interstratified with blue-black fine slate. It is easy at once to recognize, in the order given here, a likeness to the series at St. David's; indeed, the only difference observed is the occurrence of a thick bed of grit in North Wales, at the part where the Middle Arenig comes in at St. David's. This grit-bed is preceded and succeeded by fine deep-sea deposits; and the change in the character of the sediment is particularly rapid, showing that the sandstone was probably deposited in a deep sea by tidal action, and not a shore-accumulation. There is, as already mentioned, a slight difference also in the character of the sediment in the Middle Arenig at St. David's from that in the Lower and Upper series, and narrow bands of sandstone are intercalated with the slates; but the St.-David's area seems on the whole to have been almost out of the influence of the physical cause, whether tidal or otherwise, which produced this sudden change in the North-Wales series; and hence we have deposits at this period at St. David's with a fauna unknown there. The other St.-David's faunas resemble, in many particulars, those found in the series in North Wales. In Shropshire the order of the beds is almost similar to that observed in North Wales, and the Stiper Stones are doubtless, as first suggested by Mr. Salter, the equivalents of the grit beds in Carnarvonshire. Hitherto the black beds under the Stiper Stones have proved almost barren of organic remains, and they cannot be correlated with other series except by position; but in the beds immediately upon the

Stiper Stones the fauna is exceedingly like that in the Upper Arenig group at St. David's, and contains, like it, the genera *Illænus* and *Illænopsis*, in addition to most of the genera found in the beds at Ty-Obry, in Carnarvonshire.

List of Fossils from the Arenig Group, St. David's.

LOWER ARENIG.

Name.	*Localities.*
Asaphus Homfrayi, *Salt.*	Creek north of Trwyn-hwrddyn, Whitesand Bay.
Ogygia scutatrix, *Salt.*	Ditto.
Trinucleus, sp.	Ditto and Road-uchaf, Ramsey Island.
Lingulella Davisii, *M'Coy*	Ditto, ditto.
Lingula petalon, *Hicks*	Ditto, ditto.
Orthis lenticularis, *Dalm.*	Ditto.
Obolella plicata, *Hicks*	Ditto and Ramsey Island.
Conularia Homfrayi, *Salt.*	Ditto, ditto.
Didymograptus extensus, *Hall*	Road-uchaf, Ramsey Island.
—— pennatulus, *Hall*	Ditto.
—— sparsus, *Hopk.*	Ditto.
Phyllograptus stella, *Hopk.*	Ditto.
Trigonograptus ensiformis, *Hall*	Ditto.
—— truncatus, *Lapw.*	Ditto.
Ptilograptus cristula, *Hopk.*	Ditto.
—— Hicksii, *Hopk.*	Ditto.
Dendrograptus arbuscula, *Salt. MS.*	Creek north of Trwyn-hwrddyn, Whitesand Bay.
—— divergens, *Hall*	Road-uchaf, Ramsey Island.
—— flexuosus, *Hall*	Ditto and Whitesand Bay.
—— persculptus, *Hopk.*	Creek north of Trwyn-hwrddyn, Whitesand Bay.
—— diffusus, *Hall*	Road-uchaf, Ramsey Island.
Callograptus radiatus, *Hopk.*	Creek north of Trwyn-hwrddyn and Road-uchaf.
—— radicans, *Hopk.*	Ditto, ditto.
Dictyonema cancellata, *Hopk.*	Ditto.
—— Homfrayi, *Hopk.*	Ditto.

MIDDLE ARENIG.

Agnostus hirundo, *Salt.*	Slate-quarry, north side of Whitesand Bay, and south side of Porth Melgan.
Ampyx Salteri, *Hicks*	Ditto.
Æglina grandis, *Salt.*	Ditto.
—— Boia, *Hicks*	Ditto.
Calymene, sp.	Ditto.
Cheirurus, sp.	Ditto.
Ogygia peltata, *Salt.*	Ditto.
—— bullina, *Salt.*	Ditto.
Trinucleus Gibbsii, *Salt.*	Ditto.
—— Sedgwickii, *Salt.*	Ditto.
Lingula petalon, *Hicks*	Ditto.
Orthis, sp.	Ditto.
Siphonotreta, sp.	Ditto.
Theca Harknessi, *Hicks*	Ditto.
Orthoceras sericeum, *Salt.*	Ditto.
Bellerophon multistriatus, *Salt.*	Ditto.
Didymograptus patulus, *Hull*	Ditto.

Middle Arenig (*continued*).

Name.	*Localities.*
Tetragraptus crucialis, *Salt.*	Chiefly in the beds under the slate-quarry, Whitesand Bay.
—— Halli, *Hopk.*	Ditto.
—— Hicksii, *Hopk.*	Ditto.
—— serra, *Brong.*	Ditto.
Clemagraptus implicatus, *Hopk.*	Ditto.
Dendrograptus arbuscula, *Salt. MS.*	Ditto.
—— flexuosus ?, *Hall*	Ditto.
Callograptus elegans, *Hall*	Ditto.
—— Salteri, *Hall*	Ditto.
Dictyonema irregularis ?, *Hall*	Ditto.

Upper Arenig.

Æglina obtusicaudata, *Hicks*	Llanvirn slate-quarry, near Aber-eiddy.
Barrandea Homfrayi, *Hicks*	Ditto.
Calymene Hopkinsoni, *Hicks*	Ditto.
—— parvifrons, *Salt.*, var. Murchisoni, *Salt.*	Porth-hayog, Ramsey Island.
Illænus Hughesii, *Hicks*	Llanvirn quarry.
Illænopsis ? acuticaudata, *Hicks*	Ditto.
Placoparia cambriensis, *Hicks*	Ditto.
Phacops llanvirnensis, *Hicks*	Ditto.
Trinucleus Etheridgei, *Hicks*	Porth-hayog, Ramsey Island.
—— Ramsayi, *Hicks*	Llanvirn slate-quarry.
Beyrichia, sp.	Ditto.
Dinobolus ? Hicksii, *Davidson*	Ditto.
Lingula attenuata, *Sow.*	Porth-hayog, Ramsey Island.
Discina, sp.	Llanvirn slate-quarry.
Orthis, sp.	Ditto.
Ophileta, sp.	Ditto.
Pleurotomaria llanvirnensis, *Hicks*	Ditto.
Bellerophon llanvirnensis, *Hicks*	Ditto.
Theca caereesiensis, *Hicks*	Ditto.
Conularia llanrianensis, *Hicks*	Ditto.
Orthoceras caereesiense, *Hicks*	Ditto.
Buthotrepis, sp.	Ditto.
Didymograptus nanus, *Lapw.*	Porth-hayog, Ramsey Island.
—— affinis, *Nicholson*	Llanvirn quarry and Porth-hayog, Ramsey Island.
—— bifidus, *Hall*	Ditto, ditto.
—— indentus, *Hall*	Ditto, ditto.
—— patulus, *Hall*	Ditto, ditto.
Nemagraptus capillaris, *Emmons*	Llanvirn quarry.
Dicellograptus moffatensis, ? *Carr.*	Ditto.
Climacograptus confertus, *Lapw.*	Porth-hayog.
Diplograptus dentatus, *Brongniart*	Ditto and Llanvirn quarry.
Glossograptus ciliatus, *Emmons*	Llanvirn quarry.

Llandeilo Group.

The Llandeilo group, as it occurs in the neighbourhood of St. David's and throughout Pembrokeshire, may be divided into three subgroups on lithological and palæontological grounds. The *Lower Llandeilo* consists of black slates interstratified with volcanic tuff, and rests conformably on the Upper Arenig on the south coast of Aber-eiddy Bay; and the thick tuff-bed extending along that coast shows the line of junction of the two groups. In Section V. (fig. 6) the beds are nearly vertical, and the thickness of the series is about 500 feet. Two of the tuff-beds attain to a considerable thickness, while others are merely narrow lines. The thickest one, which occurs directly at the base of the series, is in part a conglomerate; but its upper portion has been pulverized and rearranged by the action of water, and made to assume a flaggy appearance. The fossil *Didymograptus Murchisoni* was discovered in the beds of this series at Aber-eiddy as far back as the year 1841, by Prof. Ramsay; and the locality has ever since been known as a favourite spot for this graptolite and for *Diplograptus foliaceus,* which occur here most plentifully and in a well-preserved state. It is only during our researches of late years, however, that any thing like a fauna has been discovered in the series; and amongst the forms recently added to it are species of *Dendrograptus* and *Ptilograptus,* also the Trilobites *Ogygia, Calymene, Trinucleus,* and *Æglina,* and the Brachiopods *Lingula* and *Siphonotreta.* The fauna is now a tolerably complete one, and it is distinct from that in the underlying and overlying series.

Middle Llandeilo.—The beds of this series, as shown in Section V. (fig. 6), rest conformably on the last, and consist of black calcareous shales and flags, and at the upper part of tolerably compact limestone. The beds occur at a high angle, with a N.W. dip. The thickness of the series, as shown on the coast, is about 800 feet; but there is every indication of a fault in the line of the Aber-eiddy valley, along the sides of which the beds occur, and that a portion of the thickness has been therefore cut off. The calcareous nature of the beds enables one easily to recognize them from the series below and above, and it also gives them a good lithological distinctness in the section. Besides this section at Aber-eiddy, they occur also in several other well-known places in Pembrokeshire, as in Musclewick Bay, on the south of St. Bride's Bay; and in the neighbourhood of Lampeter Velfrey and Llandewi Velfrey, in east Pembrokeshire, where they underlie Caradoc or Bala beds; and they are everywhere characterized by the well-known Trilobites *Asaphus tyrannus, Trinucleus Lloydii, Trinucleus favus, Calymene cambrensis,* &c. The series is therefore palæontologically and lithologically well marked and easily recognized wherever exposed.

The *Upper Llandeilo* rocks occur as black argillaceous slates, flags, and flaggy sandstones; and they rest conformably on the Upper Limestone beds of the Middle Llandeilo on the north coast of Aber-eiddy Bay, as seen in Section V. (fig. 6). The beds also lie at a high angle; and the dip is about N.N.W. The slate-quarries in Aber-eiddy Bay are near the base of the series; and the sudden change from the calcareous rock to the true argillaceous slate is very marked at this spot. When the beds of this series were deposited the conditions must have been more like those which prevailed during the Lower-Llandeilo period than in that immediately preceding; and there is evidence also in the presence of interbedded traps of a return of volcanic activity. It is difficult to know the exact thickness of the series in this section; for after attaining a thickness of over 1000 feet in natural succession, the beds are repeated, and afterwards lost on the north coast. Lithologically this subgroup differs considerably from that immediately underlying it, and also palæontologically sufficiently to warrant its being considered a distinct series. In 1841 the species *Lingula Ramsayi*, *Bellerophon perturbatus*, and *Calymene duplicata* were found in these slate-quarries by Prof. Ramsay and Mr. M'Lauchlan; but many additional species have since been discovered in the series. The fossils are very much distorted by cleavage; and it is difficult in consequence to obtain good specimens; the most characteristic species in this subgroup are *Ogygia Buchii*, *Calymene duplicata*, *Cheirurus Sedgwickii*, *Trinucleus fimbriatus*, *Ampyx nudus*, *Barrandea Cordai*, &c.

The Llandeilo group, wherever exposed in South Wales, shows almost exactly the same order of the strata as in this section at Aber-eiddy. In the so-called typical districts of Llandeilo and Builth there are no rocks of older date than the tuff beds of the Lower Llandeilo; nor have the characteristic fossils even of this series been found there; but the lithological evidence indicates the presence of the series in each place, and the fossils may doubtless be found there if carefully searched for. The calcareous or Middle Llandeilo beds are well seen in many parts of Carmarthenshire and Breconshire; and it was to this series that the name Llandeilo was first applied. The Upper Llandeilo occurs also in Carmarthenshire and near Builth, in Breconshire; and most of the fossils characteristic of the beds in Pembrokeshire have been found there. In Shropshire the whole Llandeilo group occurs in succession to the Upper Arenig, and the usual fossils are found in each of the series. In North Wales the Lower Llandeilo is found in the Arenig Mountains, in the Ffestiniog Mountains, and in the Arans, resting conformably on the Arenig group; but the evidence of the occurrence of the Middle and Upper Llandeilo series in these districts is still incomplete. The fossils, however, which have been found in beds on the east side of the Arenigs, and on the east of the Berwyn Hills, show that they are not entirely absent; and further examination will most likely prove the presence of a succession there very like that which has now been made out in South Wales.

List of Fossils from the Llandeilo Group, Pembrokeshire.

LOWER LLANDEILO.

Name.	*Localities.*
Trinucleus Ramsayi, *Hicks*	Cliffs south side of Aber-eiddy Bay.
Calymene Murchisoni ?, *Salt.*	Ditto.
Ogygia, sp.	Ditto.
Æglina, sp.	Ditto.
Lingula attenuata, *Sow.*	Ditto.
Siphonotreta, sp.	Ditto.
Bellerophon perturbatus, *Sow.*	Ditto.
Theca caereesiensis, *Hicks*	Ditto.
Didymograptus Murchisoni, *Beck*	Ditto.
——, var. geminus	Ditto.
——, var. furcillatus	Ditto.

Lower Llandeilo (*continued*).

Name.	*Localities.*
Diplograptus foliaceus, *Murch.*	Cliffs south side of Aber-eiddy Bay.
—— tricornis, *Carr.*	Ditto.
Ptilograptus acutus, *Hopk.*	Ditto.
Dendrograptus serpens, *Hopk.*	Ditto.
—— Ramsayi, *Hopk.*	Ditto.
Dictyonema, sp.	Ditto.
Nemagraptus, sp.	Ditto.
Climacograptus cælatus, *Lapw.*	Ditto.

Middle Llandeilo.

Asaphus tyrannus, *Murch.*	Aber-eiddy Bay (east side), Musclewick Bay, Llandewi Velfrey, and Lampeter Velfrey.
—— peltastes, *Salt.*	Ditto.
Calymene cambrensis, *Salt.*	Ditto.
Lichas patriarchus, *Edgell*	Ditto.
Ogygia convexa, *Salt.*	Ditto.
Trinucleus Lloydii, *Murch.*	Ditto.
—— favus, *Salt.*	Ditto.
—— fimbriatus ?, *Murch.*	Ditto.
Lingula attenuata, *Sow.*	Llandewi Velfrey.
—— granulata, *Phil.*	Ditto.
Orthis striatula, *Conrad*	Ditto.
Leptæna sericea, *Sow.*	Ditto.
Halysites catenulatus, *Linn.*	Ditto.
Stenopora fibrosa, *Goldf.*	Aber-eiddy Bay.
Bellerophon perturbatus, *Sow.*	Ditto.
Didymograptus, sp.	Ditto.
Diplograptus, sp.	Ditto.
Nemagraptus, sp.	Ditto.
Dicellograptus moffatensis, *Carr.*	Ditto.

Upper Llandeilo.

Agnostus M'Coyi, *Salt.*	Aber-eiddy Bay (north side), slate-quarry.
Ampyx nudus, *Murch.*	Ditto.
Acidaspis, sp.	Ditto.
Æglina, sp.	Ditto.
Barrandea Cordai, *M'Coy*	Ditto.
—— longifrons, *Edgell*	Ditto.
Calymene duplicata, *Murch.*	Ditto.
Cheirurus Sedgwickii, *M'Coy*	Ditto.
Ogygia Buchii, *Brongniart*	Ditto.
——, sp.	Ditto.
Trinucleus fimbriatus, *Murch.*	Ditto.
——, sp.	Ditto.
Lingula Ramsayi, *Salt.*	Ditto.
Bellerophon perturbatus, *Sow.*	Ditto.
Theca, sp.	Ditto.
Orthoceras, sp.	Ditto.
Didymograptus Murchisoni ?, *Beck*	Ditto.
Diplograptus pristis ?, *His.*	Ditto.

General Conclusions.

In the preceding remarks I have endeavoured, in addition to giving a minute description of the Arenig and Llandeilo groups, and their relation to the groups immediately above and below, to show that the sequence of the rocks of which these form a part, in the promontory of St. David's is a perfectly continuous one from the base of the Longmynd or Harlech group to the Llandeilo group, and that in this section there are no lines of division stronger than what would naturally occur in a great series deposited over a sea-bottom becoming gradually depressed, and subject to the ordinary physical influences which must have prevailed during such a change.

The palæontological record made out in these ancient rocks is shown to be more complete than has hitherto been found to be the case in any other single section; and consequently it has enabled us to recognize the proper position of groups hitherto but imperfectly defined, and to correct the limits which had been incorrectly given.

In instituting comparisons between the succession as here made out with that found in other districts, the evidence has in each case been most carefully considered, and no facts have been accepted which have not been critically examined. Some may object, however, to a comparison of sections in districts even so far apart as North and South Wales, on the ground that the deposits might possibly have been formed under somewhat different conditions; but these objections, if raised, must give way when it is considered that the Welsh area comprised only a very small proportion of the oceanic area which prevailed when these series were deposited, as indicated by the occurrence in Sweden, Belgium, France, Bohemia, and Spain on the one hand, and in North America on the other, of rocks with the same order of succession in the organic remains, and the same general sequence of beds, subject only to what might be called local differences, as of thickness &c.

There are evidences also present within small areas, such as the presence of contemporaneous lavas and ashes and of calcareous beds at certain stages in the strata, which enable us frequently, even without the palæontological evidence, to recognize readily the position of certain beds. The series may, however, on the other hand vary considerably in thickness even within a small area; and sometimes the character of the deposits may change abruptly, as in the case of the great Grit-bed in North Wales, and the Stiper Stones of Shropshire, which were evidently portions of a sandbank extending over those areas in a deep sea in which elsewhere, even within narrow limits, fine muddy deposits were being thrown down. But, taking the series collectively, these local differences are not of much importance; and they do not usually interfere with the order of the general succession so as to prevent its being easily followed out.

In the section at St. David's the strongest palæontological breaks occur at the close of the Menevian group and at the close of the Tremadoc group; and it is there I consider the chief lines for the division of the series should be placed. The Menevian group and the underlying Cambrian rocks therefore form the lowest subdivision or Lower Cambrian. For the next subdivision or Upper Cambrian I have hitherto followed Sir Charles Lyell and Mr. Salter by making it comprise the overlying series to the top of the Tremadoc group; but with the qualification now that a considerable portion of what has been called by them Tremadoc should be placed in the Arenig group. The palæontological break at this spot is tolerably strong; but, with the evidence before us of unbroken succession, it must be confessed that it is scarcely important enough to mark the dividing line between the two great systems known by the terms Cambrian and Silurian; and yet if it is not placed here, there certainly is no other break below the top of the Bala or Caradoc group which can possibly be looked upon as sufficiently important for that purpose.

Descriptions of New Species of Fossils from the Arenig Group of St. David's.

Ampyx Salteri, Hicks. Pl. X. figs. 7, 8.

A. Salteri, Hicks, Cambridge Catalogue.

This species I found several years ago in the flaggy beds to the north of the slate-quarry in Whitesand Bay; and I named it after my late lamented friend, Mr. Salter, in the Cambridge Catalogue. It occurs rather plentifully, and it is a very distinct and well-marked species. It is also one of the earliest species of the genus known, being found almost at the base of the Middle Arenig.

Description.—Nearly 2 inches long without the rostrum, and about $1\frac{2}{10}$ inch wide at the broadest part. Head equal to about one third of the whole length, triangular in shape, and moderately raised; the glabella occupies about one third of the width, is very wide anteriorly, and tapers backwards from about the junction of the anterior fourth, its sides are indented by oblique and longitudinal furrows, which mark off a pair of distinct lateral lobes; rostrum rather more than equal to the whole length of the head.

The body has a rather narrow axis of six rings. The tail is triangular in shape and strongly margined; the axis is slightly raised, has three or four rings, and reaches to the hinder border; the lateral lobes are flattened, and marked with three or four ribs.

The wide margin to the tail, and the very broad glabella distinguish this at once from any other British species.

Locality and Formation. Slate quarry at Whitesand Bay, St. David's: Middle Arenig. In collections of D. Homfray, Esq., and H. Hicks.

Trinucleus Etheridgei, n. sp. Pl. IX. fig. 6.

This well-marked species I obtained last summer from the slate-quarry near Llanvirn, and I have much pleasure in naming it after my friend Mr. Etheridge. The cleavage and bedding very nearly coincide in these slates; and therefore the specimens occur in a tolerably well-preserved state.

Description.—Length nearly an inch and a quarter, width rather less than the length. In shape ovoid, with the head-spines reaching directly backwards to a little beyond the tail. The head occupies about half the length, and, excluding the spines, is semicircular in shape. The fringe-border is nearly equally wide throughout, and has three or four rows of puncta. The glabella, which reaches the inner edge of the fringe, but scarcely indents it, is strongly convex and wide anteriorly, and tapers towards the neck-furrow; the sides are indented by two pairs of furrows, converging in the centre. The cheeks are moderately raised and like the glabella, and have the whole surface finely reticulate. The body has six rings, with a strongly raised tapering axis occupying about a fourth of the width. The tail is sharply triangular, and has a very broad margin, which is equally deep with the lobes at its widest part. Axis of five or six rings, and lateral lobes deeply ribbed.

This can scarcely be confounded with any other British species; the fimbriated border, like that of *T. Murchisoni*, has interposed a few short rays, which may tend to mislead one if the other characters are not looked into. It is, however, a much larger and wider form than *T. Murchisoni*, the tail has a stronger and wider margin, and the lobes are more distinctly ribbed.

Locality and Formation. Llanvirn quarry: Upper Arenig.

TRINUCLEUS RAMSAYI, n. sp. Pl. X. figs. 1, 2.

This species was found in the black shale at Porth-hayog, in Ramsey Island, in the summer of 1872; and specimens of it have since then been found in the black slates between the Ash beds in Abereiddy Bay. I have much pleasure in naming it after Prof. Ramsay, in whose company it was found, and to whom we owe so much for his very valuable researches amongst these ancient rocks in North Wales.

Description.—Head semicircular, $\frac{3}{8}$ of an inch long by $\frac{5}{8}$ of an inch broad; fringe-border equally wide throughout, except where indented by a convex ridge in front of the glabella; it has five or six rows of closely set puncta, and the extreme outer margin has on it a row of moderately strong spines. Glabella occupying about one fourth of the width of the head, strongly convex and pyriform in shape, and indented by two pairs of strong furrows behind. Cheeks moderately convex, and the whole surface covered over with minute puncta. The axis of the thorax is narrow and convex. The tail has not been found.

This is a very well-marked species, and differs from *T. Lloydii*, to which it is most nearly allied, in having a more evenly rounded glabella with lateral furrows, the surface of the cheeks covered over with minute puncta, the outer margin of the head covered with minute spines, and the angles scarcely at all expanded.

Locality and Formation. Porth-hayog in Ramsey Island, and Aber-eiddy Bay: Upper Arenig and Lower Llandeilo groups.

ILLÆNUS HUGHESII, n. sp. Pl.. IX. fig. 7.

The first specimen of this species was discovered some years ago by Prof. T. M'K. Hughes, at Llanrian, near Aber-eiddy; and this specimen, along with another in my possession from the Llanvirn quarry, was figured by the late Mr. Salter in his memoir (Palæontographical Soc. vol. xx.) as *Illænus perovalis.* Now, however, that further and more perfect specimens have been found, there can be no doubt that the species has been incorrectly determined. They indicate a species allied to, but yet quite distinct from, the *Illænus perovalis* of Murchison; I have therefore named the species after its discoverer. Mr. Salter's description unfortunately pertains rather to this species than to *Illænus perovalis*, from his having been misled by the specimens from near Aber-eiddy: and he has also placed its position in the series too high; for as yet it has only been found in the *Upper Arenig group*; and it has not been found associated, as there stated, with *Didymograptus Murchisoni.*

Description.—A very broad oval species, from 2½ to 3 inches long and about 2 inches broad. Head semicircular, moderately convex, and occupying rather more than a third of the whole length; the glabella is divided from the cheeks at the lower part by tolerably deep axial furrows as far as the base of the little oval glands. The eyes are separated from the glabella by a space equal to about two thirds of the width of the latter; they are of moderate size, and are situated rather near to the neck-margin. Axis of the thorax strongly raised, and separated from the lateral lobes by deep axial furrows; pleuræ longer than the axis, sharply pointed, and with the fulcrum about midway. Tail semicircular, with the front edge slightly arched; axis narrow and conical, and reaching about half the length; side-lobes moderately convex, and bounded on the outside by a wide margin.

This species is a much broader form than *I. perovalis*, has a more distinct glabella, and the eye is larger and placed nearer the neck-furrow. The position given to the eye in Mr. Salter's figures is not correct for this species, though apparently so for *I. perovalis.*

Locality and Formation. Llanvirn Quarry: Upper Arenig.

ILLÆNOPSIS? ACUTICAUDATA, n. sp. Pl. IX. fig. 5.

The genus *Illænopsis* was instituted by Mr. Salter for a form supposed to be intermediate between *Illænus* and *Asaphus*, and which had then been found only in the Arenig rocks of Shelve. The generic characters given by him are:—"Eyes remote, forward; glabella-furrows reaching the front; head not gibbous, only convex; pleuræ grooved." Our species approaches nearer to this genus than to any other; and I place it under it at present, though with some doubt. Ours also occurs in the Arenig rocks and at very nearly the same horizon as Mr. Salter's species.

Description.—Ovate in shape, about 1⅛ inch long and $\frac{7}{10}$ of an inch wide. Head semicircular, very convex, and nearly equal to one half the whole length; posterior margin arched backwards. Glabella very wide anteriorly, but narrowing rather abruptly towards the neck, axial furrows moderately strong and extending obliquely to the outer margin. Eyes large and placed at a distance equal to their length from the outer margin. Free cheek triangular in shape, and not produced posteriorly; neck-furrow deep. Thorax composed of ten rings; axis well raised, tapering gradually towards the tail, and about equally wide with the lateral lobes; pleuræ faceted and deeply grooved to the tips, which are rather abruptly pointed. The tail acutely triangular; axis strong and composed of several rings; lateral lobes raised, with a strong outer margin, which is widest opposite the axis.

The only other species known is *Illænopsis Thomsoni*; and from this our species differs in the following points: the glabella is wider, the eye much larger, and the occipital furrow reaches the outer margin much lower down; the pleuræ are more blunt, and the tail shorter and more triangular in shape.

Looality and Formation. Llanvirn Quarry: Upper Arenig.

ÆGLINA BOIA, Hicks, Cambridge Catalogue, 1872. Pl. X. figs. 9, 9 *a*.

This little species was discovered by me in the year 1865, in the Middle Arenig rocks at Whitesand Bay. The only specimen found is in the Cambridge Museum. It is a small smooth species, with no grooves or markings visible on the head and tail, and it seems distinct from any species hitherto published.

Locality and Formation. Whitesand Bay: Middle Arenig.

ÆGLINA OBTUSICAUDATA, n. sp. Pl. X. fig. 3.

The specimens of this species hitherto found are imperfect, but they are sufficient to show that it is a new species.

Description.—About 2 inches long. The head is imperfect, but it appears to occupy about half of the whole length. Thorax of six rings; axis very wide anteriorly, and tapering backwards rather suddenly, moderately raised. Anterior pleuræ very short, hinder ones increasing gradually, so that the last is about twice the length of the anterior one; they are grooved deeply and are obliquely truncate at their extremities. Tail about a fourth of the whole length, wider than long; posterior border bent slightly forward and incurved; axis conical and extending to the posterior incurved margin.

The wide short tail, with bent margin, distinguishes this from any other British species.

Locality and Formation. Llanvirn Quarry: Upper Arenig.

BARRANDEA HOMFRAYI, n. sp. Pl. IX. fig. 8.

Hitherto the genus *Barrandea* in this country has only been found in Upper Llandeilo rocks; but in Bohemia M. Barrande has found a species in his Etage D. 1, which is probably equal in age to our Upper Arenig. The present species was found in the Llanvirn quarry, and is therefore also of Upper Arenig age. I have named it after my friend Mr. Homfray, to whose researches in these older rocks we are greatly indebted.

Description.—Nearly 2 inches long, and 1¼ inch wide. The head is incomplete; but the glabella is seen to be wide, not furrowed, and separated from the cheeks by very faint axial furrows. The axis of the thorax is very wide anteriorly, and tapers sharply towards the tail. The anterior pleuræ are only equal in length to about two thirds of the opposite rings of the axis; but the hindermost ones are half as long again as the width of the axis at that part. The pleuræ are flat and grooved for about one third of their length, the fulcrum being very near the axis; they are also sharply pointed, and their whole surface is ornamented with fine lines. The tail is twice as wide as it is long, and the front arched; the axis is short and conical, prominent at the tip, and with one furrow; the lateral lobes moderately raised, with the whole surface ornamented by tolerably strong lines.

This is a very well-marked species, and it differs in several particulars from the other species hitherto known. The axis is wider at the upper part, and it tapers more regularly than in *B. Cordai*, the species which approaches nearest to it; the glabella also is much wider than it is in that species.

Locality and Formation. Llanvirn Quarry: Upper Arenig.

PLACOPARIA CAMBRIENSIS, n. sp. Pl. IX. figs. 1, 2.

This interesting species is the first of the genus found in this country, and was obtained by me from the Llanvirn quarry in August last. It resembles in some respects the *Placoparia Zippei*, Corda, found in France, Spain, and Bohemia, but is yet distinct, and it is also a smaller form. It is an important link in connecting the British with the Continental Silurian faunas; and it occurs also at about the same horizon in each country.

Description.—Ovate in shape, 1⅛ inch long and about ⅝ of an inch wide. Head semicircular and rather more than a fourth of the whole length; glabella very broad in front, occupying more than one third of the width of the head, and reaching the inner edge of the anterior margin, convex, minutely punctate and marked with three strong lateral furrows, besides the neck-furrow, the lowest being directed obliquely backwards until it nearly reaches the neck-furrow. The axial furrows are deep; the cheeks triangular, convex and rather deeply punctate. Eyes small, situated close to the glabella, and near the anterior margin; the posterior facial suture cuts across the margin at the outer angle, which is rounded. Thorax composed of twelve rings, and strongly trilobed; axis rather less than a third of the width, and tapering gradually towards the tail from about the sixth segment; pleuræ convex, with the fulcral point situated near the middle, extremities pointed and directed outwards. The axis of the tail consists of four or five strongly convex rings, and tapers suddenly to a rather sharp point, the lobes marked with four raised ribs, with their points extending beyond the margin.

The small size, the position of the fulcral point of the pleuræ, and the deeply pitted cheeks distinguish this species from *P. Zippei*, to which otherwise it is most nearly allied.

Locality and Formation. Llanvirn Quarry (near Aber-eiddy): Upper Arenig.

PHACOPS LLANVIRNENSIS, n. sp. Pl. IX. figs. 3, 4.

This species and *Phacops Nicholsoni*, Salter, from the Upper Skiddaw slates of Cumberland, are the earliest species of the genus known in this country. This species was found in the Llanvirn quarry, and therefore in beds of equivalent age to the Upper Skiddaw slates.

Description.—Oval in shape, rather more than 2 inches long by 1⅛ inch wide. Head one third of the whole length, semicircular, with the angles rounded. Glabella expanded in front and equal to one half the whole width of the head, but narrowing rapidly towards the neck until it is reduced to less than half the width. The neck-furrow is deep; and the basal furrows indent the sides to about a third of the distance across; the remaining furrows, of which apparently there are three on each side, are rather indistinctly marked. The cheeks are triangular, with a strong posterior marginal furrow; surface gently raised and smooth. The eyes small, situated near the anterior margin and close to the glabella. Thorax of eleven moderately convex rings; axis narrower than the pleuræ, widest at about the fourth or fifth segment; pleuræ deeply grooved to three fourths of their length. Tail semicircular, arched in front, moderately convex and with a tolerably distinct margin; axis conical, reaching nearly to the posterior margin and marked with eight or nine rings; the lateral lobes show four or five distinct ribs. This species differs in many points from any other British species, and can easily be distinguished by its wide and only slightly inflated glabella, and its small eyes situated far forward.

Locality and Formation. Llanvirn Quarry: Upper Arenig.

CALYMENE HOPKINSONI, n. sp. Pl. X. figs. 4, 5.

A small species, and one of the earliest of the genus known. Found by me in the Llanvirn quarry some years ago. I have named it after my friend Mr. Hopkinson.

Description.—1¼ inch long and about ¾ of an inch wide.

Glabella in length and width about equal, sides nearly straight, with three well-marked lateral furrows directed obliquely forward; apex flattened.

The axis of the thorax convex, less than a third of the whole width, and tapering regularly towards the tail.

Pleuræ flat and deeply grooved to about two thirds of their length.

The tail strongly margined, axis of eight or nine rings, and lobes marked with five or six ribs.

The glabella of nearly equal width throughout, and with the furrows directed forward, are distinguishing characters in this species, and enable it to be easily recognized from *Calymene parvifrons* and *Calymene Murchisoni*, the other species common to rocks of this age.

Locality and Formation. Llanvirn Quarry: Upper Arenig.

Dinobolus ? Hicksii, Davidson. Pl. X. fig. 6.

Mr. Davidson, F.R.S., to whom I submitted specimens of this species for examination, believes it to be more nearly allied to *Dinobolus* than to any other known genus; and he has therefore named it as above.

Description.—$1\frac{3}{4}$ inch wide by about $1\frac{1}{8}$ inch long. Central portion moderately convex, thin and flattened out at the sides and towards the anterior margin; flattened also towards the umbo, which is but very slightly produced. Surface marked with tolerably well-defined lines of growth.

This species, according to Mr. Davidson, approaches nearest in shape to *Dinobolus transversus*, Salter; but as it is from much earlier rocks than that species, it is probably distinct. It also gives the genus a much lower range than has hitherto been ascribed to it, and is interesting therefore as being the earliest known species. It is unfortunate that the material is not perfect enough for giving a proper diagnosis; but it is to be hoped, now that the beds in which it was found are under examination, that better specimens will soon be found.

Locality and Formation. Llanvirn Quarry: Upper Arenig.

Ophileta, sp. Pl. XI. fig. 3.

This is much like the specimen figured by Mr. Salter in Mem. Geolog. Survey, 1866, pl. 11 B. fig. 21; but it is too imperfect to describe or to give it a specific name. Mr. Salter's species was found in the White-Grit Mine, Shelve, and hence in beds probably of the same age as the Llanvirn beds, in which I found this specimen.

Locality and Formation. Llanvirn Quarry: Upper Arenig.

Pleurotomaria llanvirnensis, n. sp. Pl. XI. fig. 4.

Description.—Shell moderately convex, of five or six whorls, diameter about $\frac{6}{10}$ of an inch. Surface of the whorls smooth, nearly flat, and forming a gentle slope from the tolerably acute apex to the margin. On the outer edges of the whorls there is a narrow slightly raised band. This is the earliest species of the genus known in this country.

Locality and Formation. Llanvirn Quarry: Upper Arenig.

Bellerophon llanvirnensis, n. sp. Pl. XI. figs. 1, 2.

Description.—Spire of three very rapidly increasing whorls. Outer whorl greatly expanded, but compressed. Lines of growth strongly marked, arched backwards, and approximating to each other more closely in the expanded outer portion. Diameter $1\frac{1}{3}$ inch.

This well-marked species can scarcely be confounded with any other British species. Its very wide outer whorl, strong arched striæ, and compressed state are strongly characteristic and enable it to be recognized at once.

Locality and Formation. Llanvirn Quarry: Upper Arenig.

THECA CAERREESIENSIS, n. sp. Pl. XI. fig. 7.

Description.—About $1\frac{3}{4}$ inch long by $\frac{3}{10}$ of an inch wide, apex rounded. Surface covered with fine longitudinal lines. Lines of growth very indistinct. A tolerably deep furrow down the centre.

The presence of numerous fine longitudinal lines on the surface is perhaps the most characteristic feature in this species.

Locality and Formation. Llanvirn Quarry: Upper Arenig.

THECA HARKNESSI, Hicks, Cambridge Catalogue. Pl. X. fig. 11.

This is a rather small species; and the most marked character is the presence of very strong cross striæ towards the apex in addition to longitudinal ones.

Locality and Formation. Whitesand Bay: Middle Arenig.

CONULARIA LLANVIRNENSIS, n. sp. Pl. XI. figs. 5, 6.

Description.—From 6 to 7 inches long, and about $1\frac{1}{4}$ wide at the larger end, conical, with tolerably straight sides and apex pointed. One strong ridge down the centre of each surface. Lines of growth rather indistinct.

The single ridge down the centre distinguishes this species from *Conularia corium* and *C. Homfrayi*, the only species likely to be confounded with it. The former occurs in rocks of the same age in North Wales, and the latter in the earlier groups in North and South Wales.

Locality and Formation. Llanvirn Quarry: Upper Arenig.

ORTHOCERAS CAERREESIENSE, n. sp. Pl. XI. figs. 8–10.

Description.—Probably at least 6 inches long and about 1 inch wide at the broadest part. Striæ arched gently backwards, fine and closely placed. Shell very thin. This species approaches nearest to *O. Avelinii*, which occurs in rocks of the same age at Shelve, Shropshire; it differs from that species chiefly in being a wider form, and in having the lines of growth much closer.

Locality and Formation. Llanvirn Quarry: Upper Arenig.

Table showing the Range of Genera from the "Longmynd Group" to the "Bala Group" in Wales.

Genera.	Longmynd Group.	Menevian Group.	Lower Lingula-flags.	Middle Lingula-flags.	Upper Lingula-flags.	Tremadoc Group.	Lower Arenig.	Middle Arenig.	Upper Arenig.	Lower Llandeilo.	Middle Llandeilo.	Upper Llandeilo.	Bala Group.
Rhizopoda.													
Protospongia	*	*	...	...	*	*							
Ischadites	...	...	...	...	...	...	...	...	...	...	*	...	*
Hydrozoa.													
Dictyonema	...	...	...	...	?	*	*	*	...	*	...	...	*
Callograptus	...	...	...	...	...	...	*	*					
Dendrograptus	...	...	...	...	...	...	*	*	?	*			
Ptilograptus	...	...	...	...	...	...	*	...	...	*			
Trigonograptus	...	...	...	...	...	...	*						
Phyllograptus	...	...	...	...	...	...	*						
Didymograptus	...	...	...	...	...	...	*	*	*	*	*		
Tetragraptus	...	...	...	...	...	...	...	*					
Clemagraptus	...	...	...	...	...	...	...	*					
Nemagraptus	...	...	...	...	...	...	...	...	*	*	*		
Dicellograptus	...	...	...	...	...	...	...	...	*	*	*	*	
Climacograptus	...	...	...	...	...	...	...	...	*	*	*	*	*
Diplograptus	...	...	...	...	...	...	...	...	*	*	*	*	*
Glossograptus	...	...	...	...	...	...	...	...	*	?	?	?	
Actinozoa.													
Favosites	...	...	...	...	...	...	...	...	...	...	*	...	*
Monticulipora	...	...	...	...	...	...	...	...	...	...	*	...	*
Stenopora	...	...	...	...	...	...	...	...	...	...	*		
Echinodermata.													
Protocystites	...	*											
Dendrocrinus	...	...	...	...	...	*	...	...	*				
Palasterina	...	...	...	...	...	*	...	...	...	...	...	...	*
Annelida.													
Arenicolites	*	*	*	*	*	*	*	*					
Scolites	*	*	...	*	...	...	...	*					
Histioderma (Ireland)	*												
Helmintholites	...	...	...	...	...	...	...	*					
Haughtonia (Ireland)	*												
Chondrites	...	...	...	...	...	...	...	...	...	...	...	*	*
Cruziana	...	...	...	...	...	...	*						
Nereites	...	...	...	...	...	...	...	...	...	...	...	*	
Palæochorda	...	...	...	...	...	...	...	...	...	...	*	*	
Scolecoderma	...	...	...	*									
Serpulites	...	...	...	*									
Myrianites	...	...	...	...	...	...	...	...	...	...	...	*	*

Table (continued).

Genera.	Longmynd Group.	Menevian Group.	Lower Lingula-flags.	Middle Lingula-flags.	Upper Lingula-flags.	Tremadoc Group.	Lower Arenig.	Middle Arenig.	Upper Arenig.	Lower Llandeilo.	Middle Llandeilo.	Upper Llandeilo.	Bala Group.
Crustacea.													
Agnostus	*	*	*	...	*	*	*	*	*	*	...	*	*
Microdiscus	*	*											
Palæopyge	*												
Paradoxides	*	*											
Plutonia	*												
Conocoryphe	*	*	...	*	*	*	*						
Anopolenus	...	*											
Arionellus	...	*											
Erinnys	...	*											
Carausia	...	*											
Holocephalina	...	*											
Olenus	...	...	*	...	*	*	*						
Parabolina	...	...	...	...	*								
Peltura	...	...	...	...	*								
Sphærophthalmus	...	...	...	...	*	*							
Neseuretus	...	...	...	...	*	*							
Niobe	...	...	...	...	...	*							
Psilocephalus	...	...	...	...	...	*							
Asaphus	...	...	...	...	...	...	*	*	*	...	*	*	*
Angelina	...	...	...	...	...	...	*						
Dikelocephalus	...	...	...	...	...	...	*						
Cheirurus	...	...	...	...	...	...	*	*	*	...	...	*	*
Ampyx	...	...	...	...	...	...	*	*	*	...	...	*	*
Ogygia	...	...	...	...	...	...	*	*	*	*	*	*	
Trinucleus	...	...	...	...	...	...	*	*	*	*	*	*	*
Æglina	...	...	...	...	...	...	...	*	*	*	...	*	
Calymene	...	...	...	...	...	...	...	*	*	*	*	*	*
Dionide	...	...	...	...	...	...	...	...	*				
Barrandea	...	...	...	...	...	...	...	...	*	...	...	*	
Phacops	...	...	...	...	...	...	...	...	*	...	...	...	*
Placoparia	...	...	...	...	...	...	...	...	*				
Illænus	...	...	...	...	...	...	...	...	*	*	...	...	*
Illænopsis	...	...	...	...	...	...	...	...	*	*?			
Homalonotus	...	...	...	...	...	...	...	...	*	...	...	*	*
Lichas	...	...	...	...	...	...	...	...	...	...	*	*	*
Acidaspis	...	...	...	...	...	...	...	...	...	...	...	*	*
Leperditia	*	*											
Entomis	...	*											
Primitia	...	*	...	...	...	...	...	...	...	...	...	*	
Beyrichia	...	...	...	...	...	...	...	...	*	...	*	*	*
Lingulocaris	...	...	...	...	...	...	*						
Hymenocaris	...	...	*	*									
Ceratiocaris	...	...	...	...	...	...	*						

Table (continued).

Genera.	Longmynd Group.	Menevian Group.	Lower Lingula-flags.	Middle Lingula-flags.	Upper Lingula-flags.	Tremadoc Group.	Lower Arenig.	Middle Arenig.	Upper Arenig.	Lower Llandeilo.	Middle Llandeilo.	Upper Llandeilo.	Bala Group.
Brachiopoda.													
Lingulella	*	*	*	*	*	*	*						
Lingula	...	...	...	...	*	*	*	*	*	*	*	*	*
Discina	*	*	...	...	...	...	...	...	*	?	...	...	*
Obolella	*	*	...	...	*	*	*	...	*	?			
Kutorgina	...	...	...	...	*								
Dinobolus ?	...	...	...	...	...	...	...	...	*				
Acrotreta	...	...	...	...	...	...	...	...	...	...	...	*	
Siphonotreta	...	...	...	...	...	...	...	?	?	*	...	*	
Crania	...	...	...	...	...	...	...	...	...	...	...	...	*
Orthis	...	*	...	...	*	*	*	*	*	...	*	*	*
Leptæna	...	...	...	...	...	...	...	...	...	...	*	*	*
Strophomena	...	...	...	...	...	...	...	...	...	...	*	*	*
Lamellibranchiata.													
Ctenodonta	...	...	...	...	...	*	...	...	*	...	...	*	*
Palæarca	...	...	...	...	...	*	...	...	*	...	...	...	*
Glyptarca	...	...	...	...	...	*							
Davidia	...	...	...	...	...	*							
Modiolopsis	...	...	...	...	...	*	...	...	*	...	...	...	*
Redonia	...	...	...	...	...	...	...	...	*				
Ribieria	...	...	...	...	...	...	...	...	*				
Gasteropoda.													
Ophileta	...	...	...	...	...	...	...	...	*	...	...	...	*
Pleurotomaria	...	...	...	...	...	...	...	...	*	...	...	*	*
Euomphalus	...	...	...	...	...	...	...	...	...	...	...	*	*
Murchisonia	...	...	...	...	...	...	...	...	...	...	...	*	*
Heteropoda.													
Maclurea	...	...	...	...	...	...	...	...	...	...	*	*	*
Bellerophon	...	...	...	*	...	*	*	*	*	*	*	*	*
Pteropoda.													
Theca	*	*	...	...	...	*	*	*	*	*	...	*	*
Cyrtotheca	...	*											
Stenotheca	...	*											
Conularia	...	...	...	...	...	...	*	*	*	?	...	...	*
Cephalopoda.													
Orthoceras	...	...	...	...	...	*	*	*	*	*	...	*	*
Cyrtoceras	...	...	...	...	...	...	*	...	*	...	...	...	*
Plantæ?													
Buthotrepis	...	...	...	*	...	...	...	...	*				
Eophyton ?	...	...	...	...	*	*							
Oldhamia (Ireland)	*												

				ler of the ance of Life the Globe.	Localities where the Formations are Exposed.
UPPER CAMBRIAN (*Sedgwick*).	LOWER SILURIAN (*Murchison*).	LOWER SILURIAN (*Lyell &c.*).	BALA GROUP.	....	Caradoc, Horderley, Bala, Snowdon, Llandeilo, and East Pembrokeshire.
			LLANDEILO GROUP.	....	Builth and St. David's.
				....	Llandeilo, Builth, Lampeter Velfrey, Musclewick Bay, Aber-eiddy.
				....	Aran, Arenig, and Ffestiniog mountains, Shelve, Builth, and St. David's.
			ARENIG GROUP.	....	West of Arenig, Shelve, and St. David's.
				....	Carnarvonshire, Stiper stones, and St. David's.
				....	Portmadoc and St. David's.
MIDDLE CAMBRIAN.		UPPER CAMBRIAN (*Hicks*).	TREMADOC GROUP.	ozoa libranchiata, noidea, eroidea, phalopoda, ntæ ?	Neighbourhoods of Portmadoc and Dolgelly, North Wales; and Ramsey Island and St. David's, in South Wales.
			LINGULA-FLAG GROUP.	....	Neighbourhoods of Portmadoc and Dolgelly, North Wales; and Malvern.
				ropoda	Near Maentwrog and Dolgelly, North Wales; St. David's and Malvern.
				lopoda	Maentwrog and Dolgelly, North Wales; and St. David's and Solva, South Wales.
LOWER CAMBRIAN.	CAMBRIAN.	LOWER CAMBRIAN (*Hicks*).	MENEVIAN GROUP.	idea I	St. David's in South Wales, and neighbourhoods of Dolgelly and Maentwrog, North Wales.
			LONGMYND GROUP.	poda. gida. bita. nostraca. iopoda. oa. lida.	St. David's, Harlech, Bangor, Llanberis, and the Longmynds.
LAURENTIAN ?				....	St. Davids.

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* These se edded ash and tuff.

† The blac

Table showing the Order of the Succession of the Strata in Wales and Shropshire.

					Lithological Characters.	Thickness of Strata.	Fossil Contents.		Number of Fossils which range from lower to higher groups†.		Order of the appearance of Life upon the Globe.	Localities where the Formations are Exposed.
							Genera.	Species.	Genera.	Species.		
UPPER CAMBRIAN (*Sedgwick*).	LOWER SILURIAN (*Murchison*).	LOWER SILURIAN (*Lyell &c.*).	BALA GROUP.	Upper Caradoc .... Lower Caradoc	Shales and flags. Sandstones, shales, grits, calcareous bands, and interbedded ash.	feet. *4000 to 12000	120	565	......	......	....	Caradoc, Horderley, Bala, Snowdon, Llandeilo, and East Pembrokeshire.
									15	**3**		
			LLANDEILO GROUP.	Upper	Slates and flags, with interbedded traps.	*2000	20	24	......	......	....	Builth and St. David's.
									17	6		
				Middle........................	Calcareous beds. Also black ferruginous slates with calcareous bands.	1000	18	23	......	......	....	Llandeilo, Builth, Lampeter Velfrey, Musclewick Bay, Aber-eiddy.
									15	4		
				Lower	Black slates, with interbedded felspathic ashes and tuffs.	*500 to 7000	17	24	......	......	....	Aran, Arenig, and Ffestiniog mountains, Shelve, Builth, and St. David's.
									30	**6**		
			ARENIG GROUP.	Upper	Shales and slates	1500	36	65	......	......	....	West of Arenig, Shelve, and St. David's.
									19	2		
				Middle........................	Slates, flags, flaggy sandstones, and grits.	1500	22	28	......	......	....	Carnarvonshire, Stiper stones, and St. David's.
									20	3		
				Lower (Upper Tremadoc Rocks).	Iron-stained slates and flags.	1000	25	40	......	......	....	Portmadoc and St. David's
									15	**4**		
MIDDLE CAMBRIAN.		UPPER CAMBRIAN (*Hicks*).	TREMADOC GROUP.	Tremadoc Rocks.........	Dark earthy slates and flaggy sandstones.	1000	24	45	......	......	Hydrozoa Lamellibranchiata, Crinoidea, Asteroidea, Cephalopoda, Plantæ?	Neighbourhoods of Portmadoc and Dolgelly, North Wales; and Ramsey Island and St. David's, in South Wales.
									6	**4**		
			LINGULA-FLAG GROUP.	Upper. (Dolgelly Rocks and Malvern Shales.)	Soft black and bluish slates and shales.	600	10	18	......	......	....	Neighbourhoods of Portmadoc and Dolgelly, North Wales; and Malvern.
									4	2		
				Middle. (Ffestiniog Rocks and Hollybush Sandstone.)	Grey arenaceous and micaceous flags.	2000	6	6	......	.....	Heteropoda	Near Maentwrog and Dolgelly, North Wales; St. David's and Malvern.
									3	1 (?)		
				Lower. (Maentwrog Rocks.)	Bluish slates and flags, sandstones and shales.	2500	4	8	......	......	Phyllopoda	Maentwrog and Dolgelly, North Wales; and St. David's and Solva, South Wales.
									9	**2** (?)		
LOWER CAMBRIAN.	CAMBRIAN.	LOWER CAMBRIAN (*Hicks*).	MENEVIAN GROUP.	Upper .... Lower	Dark slates and flags. Dark blue and grey flags.	600	23	52	.. ...	......	Cystoidea	St. David's in South Wales, and neighbourhoods of Dolgelly and Maentwrog, North Wales.
									12	**8**		
			LONGMYND GROUP.	Harlech Grits and Llanberis Slates.	Grey grits, purple and green sandstones, slates, and conglomerates.	8000	17	25	......	....	Pteropoda. Spongida. Trilobita. Entomostraca. Brachiopoda. Polyzoa. Annelida.	St. David's, Harlech, Bangor, Llanberis, and the Longmynds.
LAURENTIAN?					Quartz conglomerate and dark green shales.	......	......	......	......	......	....	St. Davids.

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* These series vary considerably in thickness in different districts in consequence of the unequal distribution of interbedded ash and tuff.

† The black figures indicate the total number ranging up from the main groups.

EXPLANATION OF PLATES.

Plate VIII.

Map and sections showing the arrangement of the ancient rocks of St. David's.

Fig. 1. Geological Map of the neighbourhood of St. David's. Scale 1 inch to 1 mile.
2. Section from Point St. John, by St. David's, to a point near Solva Harbour.
3. Section across the N.N.E. end of Ramsey Island.
4. Section from the valley south of Tygwyn to the cliff north of St. David's Head.
5. Section from Tretio to the coast, on the east side of Aber-pwll in Abereiddy Bay.
6. Section from Cwm-wdig to the cliff of Barry Island in a line with the Geological-Survey section No. 1, Sheet 1.

Plate IX.

Figs. 1, 2. *Placoparia cambriensis*, sp. nov. From Llanvirn Quarry: Upper Arenig.
3, 4. *Phacops llanvirnensis*, sp. nov. Ditto: ditto.
5. *Illænopsis acuticaudata*, sp. nov. Ditto: ditto.
6. *Trinucleus Etheridgei*, sp. nov. Ditto: ditto.
7. *Illænus Hughesii*, sp. nov. Ditto: ditto.
8. *Barrandea Homfrayi*, sp. nov. Ditto; ditto.

Plate X.

Figs. 1, 2. *Trinucleus Ramsayi*, sp. nov. From Porth-hayog, Ramsey Island.
3. *Æglina obtusicaudata*, sp. nov. Llanvirn Quarry: Upper Arenig.
4, 5. *Calymene Hopkinsoni*, sp. nov. Ditto: ditto.
6. *Dinobolus? Hicksii*, sp. nov. Ditto: ditto.
7. *Ampyx Salteri*, Hicks. Whitesand-Bay Slate Quarry: Middle Arenig.
8. *Ampyx Salteri*, Hicks. Ditto: ditto (in Mr. Homfray's collection).
9, 9*a*. *Æglina Boia*, Hicks. Ditto: ditto (in Cambridge Museum).
10. *Agnostus hirundo*, Salter. Ditto: ditto (in Cambridge Museum).
11. *Theca Harknessi*, Hicks. Ditto: ditto (in Cambridge Museum).

Plate XI.

Figs. 1, 2. *Bellerophon llanvirnensis*, sp. nov. From Llanvirn Quarry: Upper Arenig.
3. *Ophileta*, sp. Ditto: ditto.
4. *Pleurotomaria llanvirnensis*, sp. nov. Ditto: ditto.
5, 6. *Conularia llanvirnensis*, sp. nov. Ditto: ditto.
7. *Theca caereesiensis*, sp. nov. Ditto: ditto.
8–10. *Orthoceras caereesiense*, sp. nov. Ditto: ditto.

Discussion.

Prof. Ramsay complimented the author on having brought forward a paper so well worked out. He gave an account of his own early geological work in Wales, and stated that he had mapped the rocks referred to by Mr. Hicks in 1841. He differed from the author in believing his supposed Laurentian rocks to be igneous. They were metamorphosed Cambrian deposits which had lost all traces of their aqueous origin. In 1841 no fossils had been found below the Llandeilo Flags in any part of the series described by Mr. Hicks; and then there was no ground for establishing those palæontological divisions in the series which were indicated in the present paper. He stated that he traced the line between the blue flags and the Cambrian slates, and believed that an unconformity probably exists between the Tremadoc slates and the Lower Llandeilo.

Prof. Hughes observed that the fossils by which the rocks under discussion were subdivided did not occur all through the several groups, but only in widely separated zones, and that between those zones sometimes one line and sometimes another had been taken as the arbitrary boundary, often to be shifted in consequence of the discovery of other fossiliferous bands. The line referred to by Prof. Ramsay as that which he was tracing in North Wales for the base of his Llandeilo, was a most useful line to draw, as helping to trace horizons, but was not shown to be coincident with any great break in succession. The Silurian system had not, and, after several changes, has not for its upper boundary a line representing any break in the continuity of deposition. Nor had it at first nor has it now, after much modification, any well-defined natural boundary for its base-line. The only break in it is that which occurs at the base of the May-Hill Sandstone; and that was unrecognized till pointed out by Prof. Sedgwick many years after the publication of the 'Silurian System,' the author of which, seeing that his system had no base on which to rest, took in group after group of the underlying series, and to justify himself had to prove at each step that as yet no break had been found in the series; till at length he got down to the lowest Cambrian, part of which he included in his Primordial Silurian. It was now well known, and that chiefly through the labours of Mr. Hicks, that no strong line could be drawn there, and we must therefore take it down to the bottom of the Cambrian conglomerate, or up to the base of the May-Hill Sandstone. Between these horizons lie the Cambrian rocks of Prof. Sedgwick, a well-defined natural group and an ancient name, which, following the true principles of classification and justice in our nomenclature, we must adopt.

Mr. Etheridge remarked that several species pass up from the Tremadoc into the Llandeilo, and that the line between the Tremadoc and the Llandeilo of Sedgwick was not settled. In all cases of this kind stratigraphical or palæontological evidence alone was not sufficient, the two required to be concordant. He entered at some length into the palæontological statistics of the deposits under discussion, and dwelt especially on the fact that of 70 species of fossils found in the Tremadoc, only 4 pass up into the Arenig. The break at the top of the Tremadoc was thus palæontologically of great importance, although not apparent stratigraphically. Hardly any of the Lower Llandeilo (or Arenig) species agree with those of the Llandeilo Flags. The species at the top of the Stiper have a peculiar facies of their own, and would not be recognized as Arenig.

Prof. Seeley said that the subdivisions of the Cambrian series of Sedgwick were based solely on palæontological evidence, and that to the physical geologist the deposits formed a single series, which

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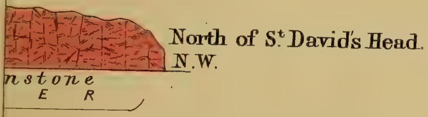
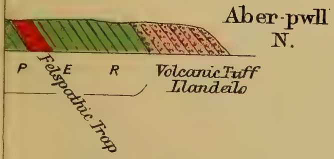
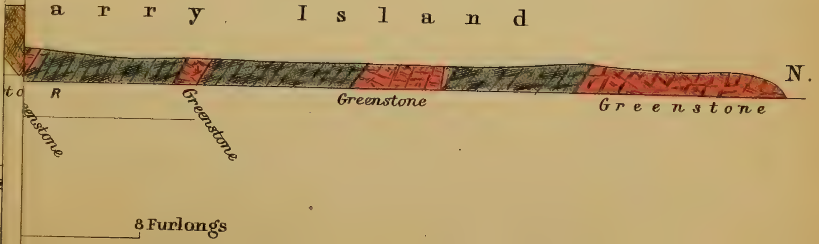




tion No. I. Sheet 1.



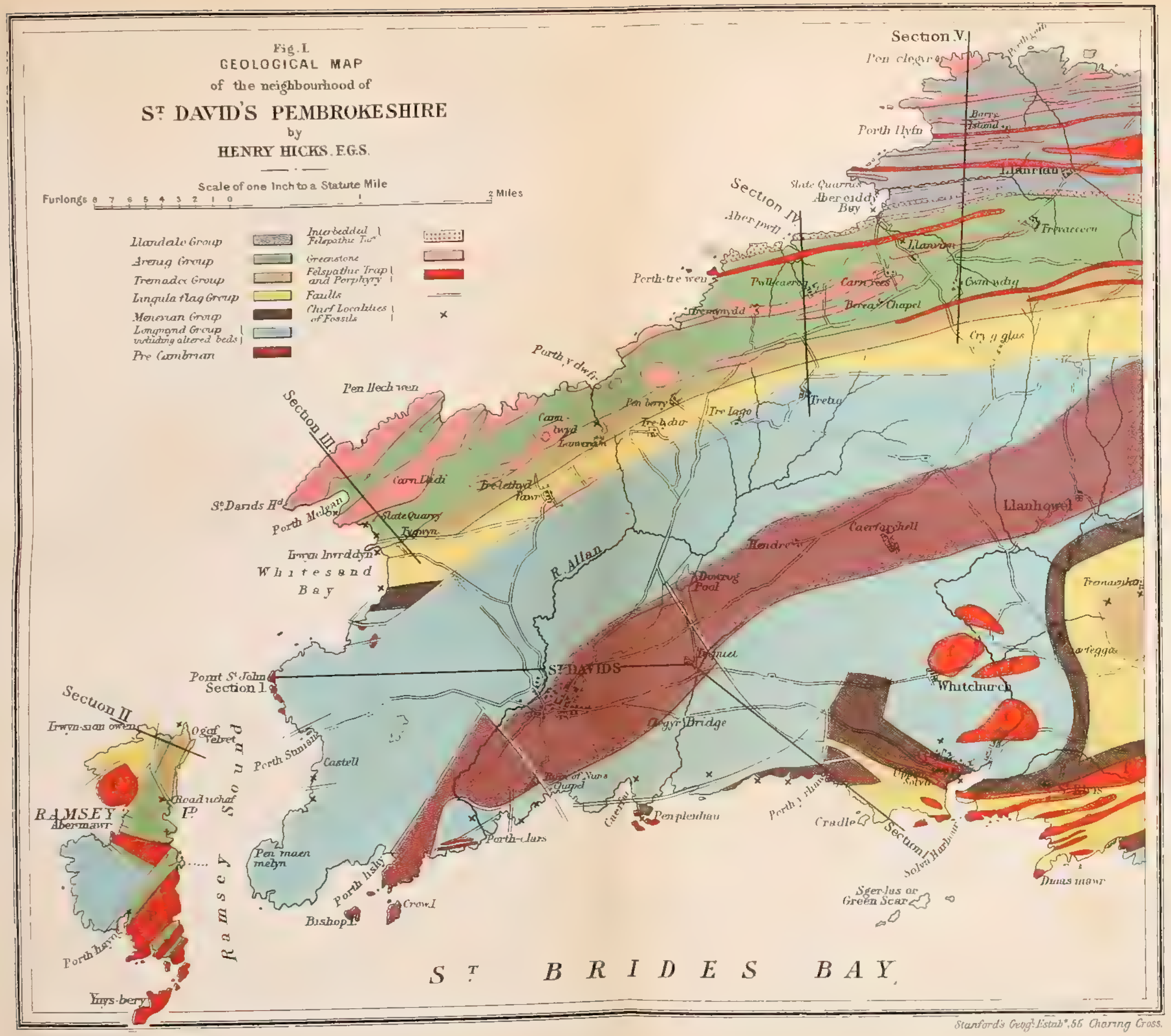


Fig. I.
GEOLOGICAL MAP
of the neighbourhood of
ST DAVID'S PEMBROKESHIRE
by
HENRY HICKS. F.G.S.

Stanford's Geog. Estabt. 55 Charing Cross.

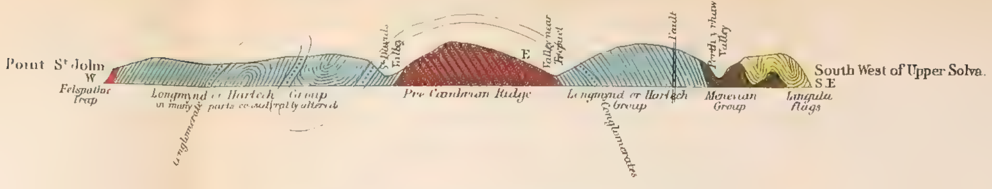


Fig 2. Section I. from Point St John W. by St David's E. to a point near Solva Harbour. S.E.

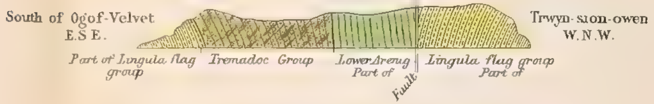


Fig 3. Section II. across the N.N.E. end of Ramsey Island.

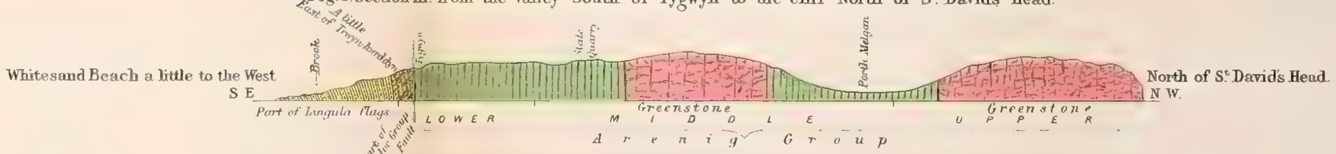


Fig. 4. Section III. from the Valley South of Tygwyn to the cliff North of St David's Head.

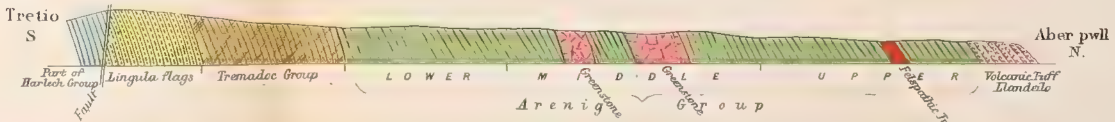


Fig 5. Section IV. from Tretio to the coast, on the East side of Aber-pwll, in Aber-eiddy Bay

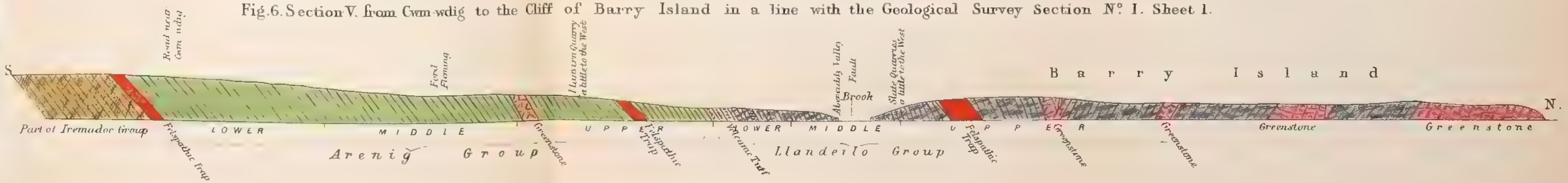


Fig. 6. Section V. from Gwn-wdig to the Cliff of Barry Island in a line with the Geological Survey Section No. I. Sheet 1.

Scale of Sections II. III. IV. V. Six Inches to a Statute Mile.
0 1 2 3 4 5 6 7 8 Furlongs

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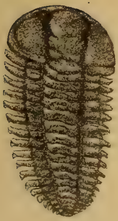

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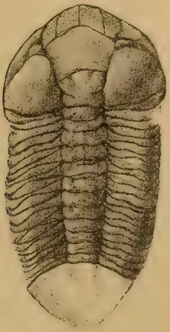

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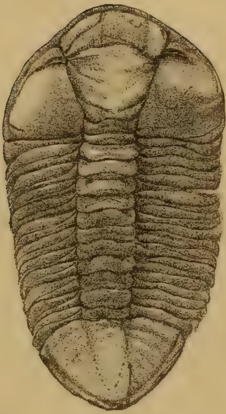

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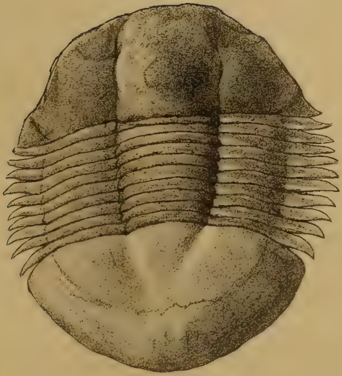

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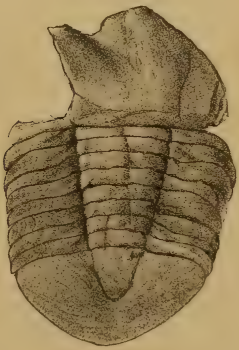

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ARENIG FOSSILS.

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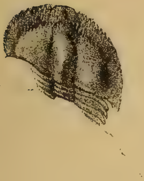

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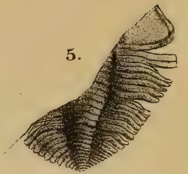

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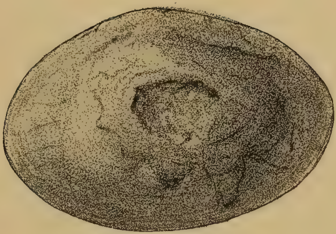

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ARENIG FOSSILS.

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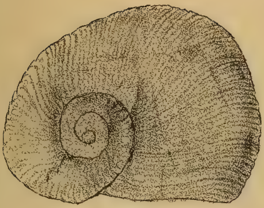

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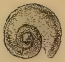

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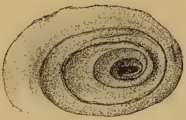

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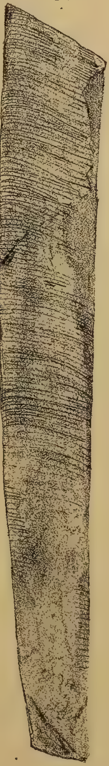

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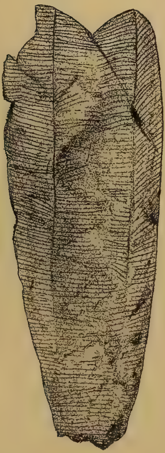

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ARENIG FOSSILS.

could be subdivided upon stratigraphical grounds. But although there was no evidence of unconformity between the strata, he thought that the fact of different groups of fossils succeeding each other in the same area showed that those groups existed in neighbouring seas, and had been driven, by upheaval of the sea-bottom on which they lived, into the region in which they are found. Hence he maintained that a change in the forms of life is evidence of unconformity in an adjoining area.

Mr. Maw remarked that under the Cambrian rocks at Llanberis there are unconformable beds, which may be the equivalents of the so-called greenstones of St. David's.

Mr. Hicks admitted that the subdivisions at present in use may need to be modified. He thought that the greatest break is between the Menevian and the Lingula Flags, few species passing from one to the other. He regarded the upper and lower portions of the Tremadoc as really distinct.

14. *On the* KIMMERIDGE CLAY *of* ENGLAND. By the Rev. J. F. BLAKE, M.A., F.G.S. (Read January 13, 1875.)

[PLATE XII.]

THE boring of the Subwealden Exploration has brought into prominence the antiquity of our information concerning the Kimmeridge Clay of England, both as to its subdivisions and as to its thickness. The only recent work done upon it is that of a foreigner, Dr. Waagen, who, studying it on the southern coast at Ringstead Bay and at Weymouth, proposed a new classification, which has been followed by Mr. Judd in his valuable paper on the Speeton clay. With this exception we have to go back to the days of Conybeare and Buckland for information on the subject; and it has been impossible for foreign authors to correlate satisfactorily their Kimmeridgian beds with ours. Dr. Waagen's paper is brief and incomplete; and there thus seemed room for useful observation on this subject. Both the above-named authors, as well as Professor Phillips and Mr. Damon, have made additions to our list of fossils; but the two latter have only indicated local subdivisions in the beds.

On the Continent, though much diversity exists in the arrangement of these beds (each separate locality having palæontological features which, to a certain extent, render unavailable the classification founded on others), the general result is their separation into three zones—the lowest that of *Astarte supracorallina*, or the Astartian, and the middle that of *Pterocera Oceani*, or the Pterocerian. On these two there is considerable uniformity of opinion; while the upper, more or less developed in various localities, is either included in the zone of *Trigonia gibbosa*, or the Portland strata, or separated as the zone of *Exogyra virgula*, or the Virgulian. Oppel, in his 'Juraformation,' p. 727, while correlating the English Kimmeridge Clay in general with the zone of *Pterocera Oceani*, states that he recognizes some of the beds at the base as belonging to the Astartian zone, but without further particularizing them. He, however, recognized no horizon in the Kimmeridge Clay above that of *Pterocera Oceani*, but called his next zone that of *Trigonia gibbosa*.

Waagen to a certain extent follows this classification, assigning 500 feet, or the main mass, to the middle region, to which he assigns a new name, that of the Zone of *Ammonites mutabilis* and *Exogyra virgula*. He marks off in the section at Sandsfoot Castle, near Weymouth, certain beds as Astartian, or, as he calls it, the Region of *Ammonites alternans* and *Rhynchonella inconstans*, and makes the advance of separating the upper portion as a distinct zone. He seems to regard this as higher than the Virgulian or equivalent beds, and as characterized by the absence of *Exogyra virgula*. This classification, from its adoption by Mr. Judd, may be considered that at present accepted. Detailed observations in Lincolnshire and on the coast of Dorset have suggested to me some necessary alterations.

The names Astartian and Pterocerian seem to be without substantial objection; but the upper portion has had no corresponding name generally assigned to it. In the Kimmeridge Clay, however, though the various portions are well separated by their general assemblage of fossils, yet many fossils which in one locality are highly characteristic of a particular portion, are absent in that portion in another locality, and characterize instead a higher or a lower zone. Thus *Exogyra virgula* in the Jura bernois and elsewhere is characteristic of the upper portion; at the Cap de la Hève it occurs throughout; and in England it is wanting only in the upper part, or sometimes, as in Lincolnshire, appears to be absent entirely. So, again, *Rhynchonella inconstans*, which is the characteristic species of the lowest beds in England, in the environs of Montbéliard* is found in all *but* the lowest, and most frequently at the top, and has not been met with in the Subwealden boring. On account of this peculiarity of the distribution of Kimmeridgian fossils, it is better to use the more general terms—lower, middle, and upper.

I am not, however, attempting in this paper to correlate our English Kimmeridge Clay with the many subdivisions of that formation adopted by foreign authors, but rather to show into what palæontological and lithological subdivisions it may naturally be separated by a study of its features in the field.

I hope to be able to show that there are only two series of beds sufficiently distinct to justify their separation under different titles, the upper of which agrees with that of Dr. Waagen, but the lower includes his middle region and part of his lower, while the remaining part of his lower region, and possibly part of his zone of *Cidaris florigemma*, constitute a series of beds which from their containing as much of a Corallian as of a Kimmeridgian fauna, I designate as the Kimmeridge passage-beds.

The different divisions I now proceed to describe.

Upper Kimmeridge.

The Upper Kimmeridge Clay (*Virgulien* of foreign authors) is distinguishable both lithologically and palæontologically from the zones below. It is here exclusively that the bituminous shales, paper-shales and cement-stones occur, except in the Subwealden boring, where they occur throughout. They contain a comparative paucity of species, but an infinity of individuals. In the thin paper-shales each leaf is covered with the white compressed shells of an Ammonite, *Discina latissima*, and *Lucina minuscula*; and there cannot be less than 20 leaves to an inch. This is more especially seen in Lincolnshire, as at Fulletby; for in Dorsetshire the fossils are more often comminuted, though the layers are thinner. Whatever length of time we may assign to the deposition of each layer, with its separate shells, the whole mass, when traced along the shore, cannot fail to give an extended idea of the total amount of time involved in its formation.

These laminated and bituminous clays are more limited in extent

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* Contejean, 'Étude de l'étage Kimméridien,' 1859.

than the lower beds, and appear to be nowhere so completely developed as in Kimmeridge Bay and the coast to the east, the strata in that locality belonging almost exclusively to this division, proving that by no means all of the formation is here exhibited (as Fitton supposed), though its upper portion is here extraordinarily developed. I have carefully measured the beds in this coast-section as far as accessible; and though cut through by many small faults, their succession is very plain, and gives a total thickness of this portion of the series of 650 feet, which may be regarded as the maximum in exposed sections.

The following is the section, omitting the minor details; and the beds gradually dip to the east. This section begins where the highest beds are seen, and goes westward:—

Section on the Coast at Kimmeridge, between Chapman's Pool and Hen Cliff.

Lithology.	Thickness.		Observations.
	ft.	in.	
Ragged limestone blocks......	22	0	Thickness estimated. Inaccessible here.
More stratified limestone......	20	0	„ „
Black slaty limestone?	44	0	„ „
Bluish white fine-grained limestone	2	0	„ „
Blue slaty limestone	24	0	„ „
Hard blue limestone	4	10	
Hard blue sandy clay	150	0	Unfossiliferous down to this level and gradually changing into the next.
1. Blue laminated clay...........	70	0	*Am. biplex*, *Astarte lineata*, *Bel. Souichii*.
2. Hard slaty shale	2	0	Fossiliferous.
3. Soft shale, with indurated bands	77	0	*Am. biplex*, *Exogyra*, *Leda*, *Belemnites Souichii*, *Lima*, sp., *Ostrea*; measured obliquely, and estimated.
4. Dicey clay.........................	12	0	Fossils in layers.
5. Hard band	2	0	
6. Blue clay	24	6	*Cardium striatulum*, *Avicula vellicata*, *Am. biplex*, *Pecten lens*.
7. Dark and sulphurous clays...	18	6	Fossiliferous bands and large nodules.
8. Indurated band	2	0	
9. Blue laminated shales, indurated in the middle ...	20	6	*Discina latissima*, *Lingula ovalis?*
10. Hard white slab, with paper-stratification	1	6	
11. Softer shale, alternating with white paper-slabs...	23	6	
12. Very solid paper-slab	2	0	
13. Blue dicey clay..................	4	6	
14. Cement-stone	1	2	
15. Blue dicey clay..................	2	6	
Forward	263	8	

Section on the Coast at Kimmeridge (continued).

Lithology.	Thickness.		Observations.
	ft.	in.	
Brought forward	263	8	
16. Cement-stone	0	9	
17. Blue clay with indurated band	14	0	
18. Cement-stone, dicey	1	6	
19. Blue clay	2	6	
20. Solid white paper-shale	6	0	
21. Blue clay, with irregular bands of hard limestone	8	6	
22. Dark papery shales, with many indurated bands	22	3	
23. Blue dicey clay, with indurated bands	27	6	
24. Cement-stone	3	9	
25. Hard blue dicey clay	55	0	Thickness partly estimated, not less than this.
26. Dark bituminous clay, with courses of speckly limestone	22	8	The lower part worked for the shale.
27. Softer, more laminated shales, with indurated bands	25	0	*Am. biplex, Lucina minuscula.*
28. Blue dicey clay	14	0	Thickness estimated.
29. Double hard band, bituminous	5	6	
30. Hard blue clay, with indurated band	20	0	
31. Cement-stone	2	4	Worked for cement.
32. Dicey clay	15	0	
33. Laminated clays, with indurated bands	19	3	
34. Cement-stone	1	9	
35. Laminated bituminous shales	41	6	
36. Irregular blue sandy limestone	1	6	
37. Clay, with indurated bands	11	6	
38. Hard blue slaty beds	1	4	*A. biplex, A. Thurmanni, Cardium striatulum, Discina latissima, Exogyra virgula, Aptychus, Astarte lineata, Lucina minuscula, Arca rhomboidalis?*
39. Hard blue shales, with indurated bands	13	0	
40. Hard bituminous shales, with indurated bands	11	10	*Cardium striatulum, Discina latissima.*
41. Hard blue shale	20	9	*Cardium striatulum, Lucina minuscula, Exogyra virgula, Rostellaria*, sp.
42. Cement-stone	0	9	
43. Hard dicey shale	18	6	*Cardium striatulum, Exogyra virgula.*
	651	7	

Here the eastern corner of Kimmeridge Bay is reached, and the continuation of the beds is not distinct. There *may* be a fault running E. and W.; and the beds which skirt the bay *may* represent part of the above, though I cannot correlate them, and they are themselves faulted so as to disturb the continuity. If, however, all the beds here really lie below those described above, we should have 138 ft. more to add; and some of them are certainly distinct, *e. g.* a double hard sandy bed 1 ft. 9 in. thick, separated by dark papery shales. Leaving these, however, out of consideration, we have in the above section a continuous series of beds with the same kind of lithological features, namely well-stratified shaly beds, differing in this respect from the lower portions of the Kimmeridge Clay—fossiliferous at the top and bottom, and less so in the middle, but containing *Discina latissima* and *Lucina minuscula* throughout, both highly characteristic Upper Kimmeridge fossils, with abundance of *Cardium striatulum*—*Exogyra virgula* coming on below, and probably indicating that we are not far above the lower beds. Indeed its occurrence with *Discina latissima* indicates a passage-bed from one division to the other; and therefore some portion at least of the 138 ft. in the bay ought rather to be classed as Lower Kimmeridge, although if we are guided by the useful rule generally adopted in the case of overlapping faunas to decide the name of the beds by the lithological features, we should class them all with the upper.

Be this as it may, all the beds from No. 40 upwards must certainly be reckoned as Upper Kimmeridge, and correspond to the region of *Discina latissima* and *Acanthoteuthis speciosa* of Waagen, which may thus reach, instead of 100 ft., as he states, a total thickness of 650 ft.

Buckland estimated the thickness here at 700 ft., which was pretty near the truth; for I have drawn the upper line in the midst of clays, where they become fossiliferous, and are undoubtedly Kimmeridgian, and some portion probably of the 138 ft. should be added below.

Two zones of life may be remarked, the lower being characterized by the presence of *Amm. Thurmanni* and *Exogyra virgula*, the upper by a different set of the rarer fossils and the abundance of *Astarte lineata*; but these zones are not continuous over large areas.

Going west to Ringstead Bay, whence Waagen took his section, not more than 100 ft. of these beds appear; but whether from their non-existence, or the presence of another fault, not marked on the Survey Map, is doubtful. At this level below the Portland Sand the clay becomes uniform, without marked stratification, contains Lower Kimmeridge fossils, and is quite different in appearance from any further east. The whole cliff, however, is so broken that no accurate knowledge can be really obtained of the thickness and lie of the beds.

Upper Kimmeridge, with bituminous shales, is known to occur in Portland, though I doubt if some of the fossils quoted by Damon really belong to it.

In the inland counties* it is either very thin or absent, as there is very little room for it at Swindon between the Lower Kimmeridge and the Portland Sand, as is also the case at Hartwell;

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* By inland counties I mean Wiltshire, Oxfordshire, and Buckinghamshire.

but it is certainly present at Shotover, though much thinner than in Dorsetshire.

At Ely very little is seen of the Upper Kimmeridge; for although not more than 32 ft. of strata are exposed, the upper portion is papery and bituminous, and contains *Lucina minuscula*, *Discina latissima*, *Cardium striatulum*, with other fossils; while below the more clayey beds contain *Amm. serratus* and other species characteristic of Lower Kimmeridge, *Exogyra virgula* forming a whole band intermediate between them and going up into the shales.

This last fossil, though met with at intervals through all the Dorsetshire Lower Kimmeridge, is nowhere so plentiful as it is here, where it might almost justify the title Virgulian for the beds; and we may thus perhaps regard its abundance as marking the passage from Lower to Upper Kimmeridge.

In Lincolnshire the upper beds are again well developed, and are continuously seen in pits or hill-side sections. They skirt the base of the hills by Bolingbroke and Spilsby to the south of these towns, where *Astarte lineata*, *Avicula vellicata*, *Lingula ovalis*, and *Discina latissima* have been collected by Mr. Keeping in the slaty beds, and in the clay beds above them I have found *Amm. biplex* and *Lucina minuscula*.

Near Fulletby, west of the hill bounding the valley to the west of the village, the Upper Kimmeridge is well displayed in a brick-yard, where 15 ft. or more of bituminous paper-shales with large limestone doggers near the top are seen. This is a good locality for the fossils of the series, as they are very varied and numerous, exemplifying well the remark before made on each thin layer having its own fossils.

The fossils here obtained are:—

Ammonites biplex, *Sow.*
Aptychus biplex.
Belemnoteuthis.
Trochus retrorsus, *Bla,*
Dentalium Quenstedti, *Bla.*
Lucina minuscula, *Bla.*
Astarte lineata, *Sow.*
Pecten lens, *Sow.*
Cardium striatulum, *Sow.*
Avicula vellicata, *Bla.*
Gervillia tetragona, *Röm.*
Ostrea gibbosa, *Les.*
Discina latissima, *Sow.*

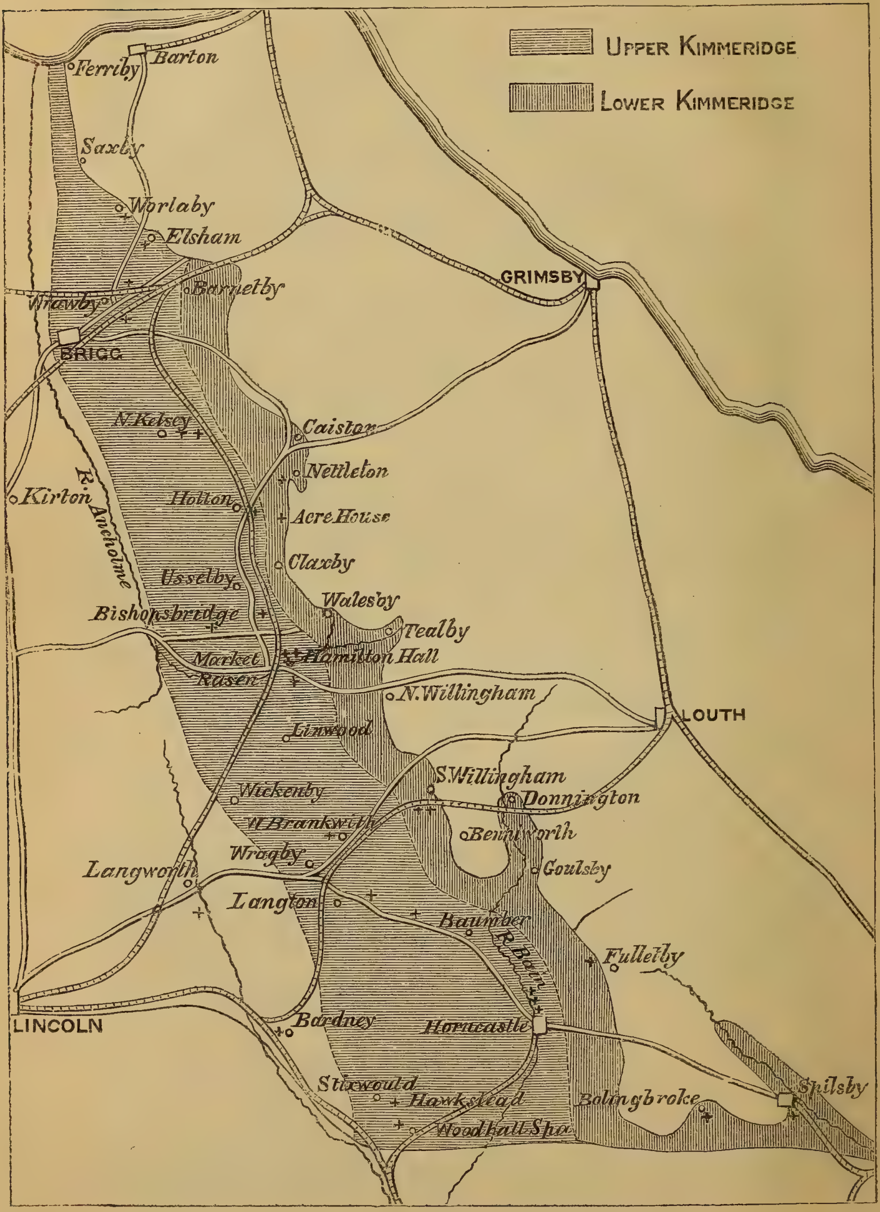
About four miles north of this, in the valley of Goulsby, where it lies in a long tongue scooped out by the river Bain, it is again seen in a brick-yard. It is here brought very close to the Red Chalk; but the succession of sandstone, ironstone, clay and sandstone may be traced between them.

The beds here would appear to be lower in the series, the section being

Papery shales, 9 in.,
Blue dicey clay, 3 ft. 4 in.,
Harder fossiliferous band, 1 ft. 6 in.,
Blue clay, 14 ft., with nodules at the base,

thus showing the characters of the lower series. The fossils, however, are *Amm. biplex*, *Lucina minuscula*, *Ostrea gibbosa*, *Discina latissima*, and *Belemnoteuthis antiquus* (?), two fine specimens of

Sketch Map of part of Lincolnshire, showing the positions of the various Clay-pits in the Kimmeridge Clay.



the latter having been procured by Mr. Keeping for the Cambridge Museum.

In the cuttings of the Louth and Lincoln Railway we get again the succession of some of the beds. The actual junction with the Neocomian I did not see, as it was covered by drift. In the next cutting to the west we have the following section:—

Thin limestone band, 4 in.
Blue shale, 9 ft.
Hard band of hydraulic limestone, 8 in., with *Ammonites pectinatus* (Ph.), *Lucina minuscula*, *Ostrea gibbosa*, and *Discina latissima*.
Light blue dicey clay, with shale full of *Lucina minuscula*.

The same papery shales with numerous fossils (*Amm. biplex*, *Cardium striatulum*, &c.) occur in the next two cuttings; and probably intermediate to them are the soft blue, not very fossiliferous, clays of a brick-yard by the railway-side, with *Amm. biplex*, *Lucina minuscula*, and *Ostrea gibbosa*; in this case, where we have the most complete section, we are struck with the general resemblance of the series to that at Kimmeridge; and this is the more noticeable, because the next good exposure, that at Nettleton Hill, shows us clays above the paper-shales, which are less and, indeed, scarcely fossiliferous, perhaps 30 ft. in thickness. The paper-shales here, *i. e.* at Acre House, are very fossiliferous, and yield *Discina latissima*, *Belemnoteuthis*, *Ammonites pectinatus*, *Avicula vellicata*, and *Homomya gracilis* (?). The series here, however, though possibly complete, cannot be so thick as in the south, as the Lower Kimmeridge is met with at the base of the hill at Holton-Moor station, and the dip is certainly not great.

I have not traced these beds further north; but Mr. Judd records their recurrence, after having been covered by the Chalk, in Filey Bay, where they contain the same fossils, together with *Lingula ovalis* in abundance, which, in spite of Dr. Waagen's quoting it as characteristic, I have everywhere else found to be a rare fossil in the Upper Kimmeridge, and to characterize rather the lower portions.

Everywhere then, as already remarked by Mr. Judd, the uppermost portion is thinly stratified and slaty. The contained suite of fossils have quite a facies of their own. We remark the commonness of *Aptychi* and Teuthiform Cephalopods. *Discina latissima* seems absolutely characteristic, although Prof. Phillips records a fossil by that name from the Oxford Clay. *Astarte lineata*, and *Avicula vellicata*, though rarer, also seem peculiar. *Lucina minuscula* is the bivalve that seems hitherto to have escaped description, and which crowds every surface; and though it is also met with far more rarely in the lower beds, by its abundance here it becomes really characteristic. The *Cardium striatulum* is the *C. lotharingicum* of Waagen's list, and, though more abundant in the upper beds, is scarcely characteristic, unless indeed we ought to divide the species. The remaining fossils are either rare or are also met with in lower beds; but their number is few. Of the whole list of Mollusca, containing 21 certain species, 14 are peculiar, and 7 are common to lower or higher beds—one, *Ammonites pectinatus* (Ph.), occurring also in the

Portland rock. The number of those that pass upwards is no doubt really greater where the two sets of beds are fully developed.

It thus appears that the upper portion of the Kimmeridge Clay can be satisfactorily marked off by lithological and palæontological characters into one connected series, and has therefore good claim for recognition. The sequel will show how far it is distinct from the beds below.

Lower Kimmeridge.

The lower series consists of thick beds of clay, offering little lithological distinction, except in the neighbourhood of the Coral Rag; and if they are divided at all, it must be palæontologically. Dr. Waagen does this, including in the Lower Kimmeridge some feet of the clays at the base, and calling the rest Middle Kimmeridge; and Mr. Judd, in his paper on the Speeton Clay*, follows him for the strata of Filey Bay, and indicates the Lincolnshire pits which he considers to belong to either region.

The only positive indication of the nature of the Middle Kimmeridge, which Dr. Waagen states at 500 ft. thick, and which therefore ought to be the main mass and most often met with, is his list of 12 fossils, which, he says, are such as are commonly met with on the Continent in the zone of *Pterocera Oceani*. Of these, however, 4 (viz. *Amm. mutabilis*, *Panopæa tellina*, *Opis suprajurensis*, and *Exogyra nana*) he himself records from the lower beds also. Of the remainder, *Amm. Berryeri* and *Lucina Elsgaudiæ* (*substriata*) occur in the lowest beds at Weymouth; the *Pholadomyæ* (2) are so badly preserved in the Kimmeridge Clay, as well as scarce, that it is impossible to place much reliance on them. *Cardium pseudoaxinus* is quoted by Thurmann from the lower zone also, and is certainly rare. *Exogyra virgula* occurs throughout.

There are left *Rostellaria nodifera* and *mosensis*, the latter of which is certainly most common in the upper portion; but they do not appear to be universally characteristic of the zone of *Pterocera Oceani*.

There is therefore nothing special about this collection of fossils which would justify the separation of the beds from those below; in fact, the different species are so united by occurring together in various localities, that two different faunas cannot be made out; and though minor zones may be recognized, as in the Upper Kimmeridge, they are often very local.

Judging, as we must do, for the general correlation of the beds, by the general assemblage of the fossils, it appears to me that the Middle Kimmeridge (that is, a series of beds containing a special Middle fauna, as exhibited elsewhere) is absent from England, although, the deposition of the beds having been continuous, some of them must be undoubtedly contemporaneous with the Middle period. The special fauna is that which abounds in Gasteropods of the genera *Pterocera*, *Nerinæa*, *Natica*, and *Chemnitzia*, together with many varieties of *Panopæa* and *Pholadomya*, and in some cases various

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* Quart. Journ. Geol. Soc. vol. xxiv. p. 240.

Echinoderms. Only the discovery of such a fauna would justify the recognition of Middle Kimmeridge beds.

All the rest, then, I include under the title Lower Kimmeridge, with the exception of a few beds forming the passage from the Coral Rag. Undoubtedly we might call the latter Lower Kimmeridge and all the rest Middle, as it would appear that Oppel would have done; but there are objections to this. In the first place, the thickness of these passage-beds is quite inconsiderable compared with the others; they are also only developed, as it would appear, where the Coral Rag is present, and contain in a large proportion a Coralline fauna; but, chiefly, the fossils of the clays above them do, and *their* fossils do not, bear comparison with those of the zone of *Astarte supracorallina*, as will be seen in the sequel.

The series may be best studied inland, particularly in Lincolnshire, which agrees with Dorsetshire in this as in the upper part.

The Horncastle pits, cited by Mr. Judd as belonging to the Middle Kimmeridge, are three in number. They expose some thickness (30 feet) of clay, with a few septarian stones, which, however, are not very fossiliferous. They probably belong to the uppermost region, as I could not find in them any examples of *Amm. serratus*. They contain, however, fossils associated with that Ammonite elsewhere; and its absence only marks a region in the series. The fossils here obtained are:—

Ammonites mutabilis, *Sow.*
Rostellaria mosensis, *Buv.*
Dentalium Quenstedti, *Bla.*
Cerithium crebrum, *Bla.*
Cardium striatulum, *Sow.*
Lingula ovalis, *Sow.*
Avicula ædilignensis, *Bla.*
Pecten Grenieri, *Cont.*
Astarte supracorallina, *D' Orb.*
Nucula Menkii, *Röm.*
Nucula, sp.
Corbula Deshayesia, *Buv.*
Arca reticulata, *Bla.*
Anatina minuta, *Bla.*
Homomya compressa, *Ag.*
Thracia depressa, *Sow.*
Serpula intestinalis, *Ph.*

We see at once that this is a fauna quite distinct from that of the upper beds at Fulletby, two miles to the N.E., and that we have reached a region as distinct palæontologically as it is lithologically. As these pits, from their stratigraphical position, as well as their contained fossils, are certainly as high in the Lower Kimmeridge as any seen in Lincolnshire, it is important that we should examine this list, incomplete as it no doubt is, to see if it affords any justification for a separation between the beds here and the lower ones at Market Rasen and elsewhere. Now, of the seventeen here quoted, every one is found in company with *Amm. serratus* in other pits in Lincolnshire; and I fully believe a longer search would reveal that Ammonite here. Three also, namely *Avicula ædilignensis*, *Thracia depressa*, and *Serpula intestinalis*, go down to the very lowest beds. This set of pits, therefore, cannot be separated from the rest; are they all, then, to be called Lower, or Middle Kimmeridge?

Bearing in mind the different horizons of species, as before mentioned, in different localities, which will account for the presence of *Rostellaria mosensis*, although it is not a very common fossil here, we find among the remainder, first, the very species that gives its name to the Astartian zone, *Astarte supracorallina*—and, again, *Corbula Deshayesia* and *Nucula Menkii*, the first of which is always, and the second usually, characteristic of lower beds; and these, with *Cerithium crebrum*, are the common fossils. The latter is a near ally, if not a variety, of *Cerithium limæforme* (Röm.), which is also characteristic of the lower beds. Thus, standing alone, these pits seem to me to present a fauna comparable to the Lower and not to the Middle Kimmeridge; and if they are not to be separated from the beds with *Amm. serratus*, the conclusion becomes more certain.

If these are Lower Kimmeridge, the rest, of course, are also, and we need only a description, and not so particular a discussion of their fossils.

The next exposures of this upper portion are at the south side of the Louth road at Market Rasen, and at Hamilton Hill, near that place. No clear section is here seen; but a rather peculiar fauna is found in the large septarian doggers scattered about, and which are generally formed round large Ammonites, such as *Amm. Berryeri*. Several series of such doggers, some more septarian than others, are found in the various clay-pits. The fossils here are:—

Ammonites Berryeri, *Les.*
—— biplex, *Sow.*
—— yo ?, *D'Orb.*
Nucula obliquata, *Bla.*
Avicula nummulina, *Bla.*
Rhynchonella pinguis, *Röm.*
Astarte supracorallina, *D'Orb.*

In the cutting east of Brigg, at the most easterly portion, is seen dark clay, which contains similar fossils to those at Horncastle, viz.:—

Rostellaria mosensis, *Buv.*
Cerithium forticostatum, *Bla.*
Anatina minuta, *Bla.*
Exogyra nana, *Sow.*
Lingula ovalis, *Sow.*
Arca reticulata, *Bla.*
Ostrea dilatata, *Sow.*
Discina elevata, *Bla.*
Serpula intestinalis (?), *Ph.*

In the Wrawby cutting the beds are now too rotten to give much chance of seeing fossils; in the most easterly portion, however, occurred *Amm. biplex*, *Astarte supracorallina*, *Cerithium crebrum*, *Nucula Menkii*, *Serpula tetragona*, and *Pentacrinus*, sp.

The above exposures are in descending order; and we see in them the gradual introduction of species that occur more abundantly below, though the region of *Amm. serratus* is not yet reached; there is, however, nothing in them that would justify their separation from the beds below as Middle Kimmeridge.

Yet they have a facies in common that may serve to separate them as a subzone, namely the absence or rarity of *Amm. serratus* and the presence of abundance of *Rostellaria mosensis* and *Anatina minuta*. This latter character does not hold for the two pits mentioned near Market Rasen, whose peculiar fossils prevent their correlation; but they are probably the lowest of all these.

The beds above mentioned, in the Wrawby cutting, are succeeded by some thickness of very gypsiferous, but unfossiliferous, clays, the joints of which weather yellow. The occurrence of gypsum in the Kimmeridge clay is also mentioned by Prof. Phillips ('Geology of

Oxford,' p. 325); and the beds of this mineral met with in the sub-Wealden boring may possibly belong to the uppermost portion of the formation. This is one gypsiferous zone; there is another below, seen at Hawkstead.

Following on this, at the Wrawby-road bridge, are the clays with *Amm. serratus* and associated fossils. We here reach the region most interesting by its organic remains, which are in great variety and tolerable abundance. Pits in this zone are numerous, though not all containing the same fossils.

At Wrawby occur the following:—

Ammonites biplex, *Sow.*
—— serratus, *Sow.*
Thracia depressa, *Sow.*
Lucina minuscula, *Bla.*
Anatina minuta, *Bla.*
Astarte supracorallina, *D'Orb.*
Trigonia Juddiana, *Lyc.*
Avicula ædilignensis, *Bla.*
Arca reticulata, *Bla.*
Lingula ovalis, *Sow.*

At Market Rasen, on the north side of the Louth road, is the pit in this region which appears to be opened on its most fossiliferous part; and from this and another on the Walesby road, nearly on the same horizon, but a little lower, have come most of the Lincolnshire Kimmeridge-clay fossils of late years. It is covered by a few feet of sand redeposited from superjacent beds; and then we have 17 feet of blue clay most fossiliferous towards the base, 6 inches of septarian limestone, and blue clay 2 feet. The best fossils lie nearest to the limestone, above and below, but not in any well-marked horizons. The commonest, besides the *Ammonites cymodoce*, *decipiens*, and *serratus*, are the characteristic *Astarte*, a new species of *Cerithium*, *Nucula Menkii*, and *Thracia depressa*. *Ostrea deltoidea*, though present, is very rare, as is also *Lingula ovalis*. The complete list, richer than from any other locality and containing several new forms, is as follows:—

Ichthyosaurus, sp.
Teleosaurus, sp.
Ammonites decipiens, *Sow.*
—— mutabilis, *Sow.*
—— ? rotundus, *Sow.*
—— cymodoce, *D'Orb.*
—— Berryeri, *Les.*
—— serratus, *Sow.*
Belemnites nitidus, *Dollf.*
Cerithium crebrum, *Bla.*
—— forticostatum, *Bla.*
Rostellaria rasenensis, *Bla.*
Natica microscopica, *Cont.*
—— punctulata, *Bla.*
Tornatella secalina, *Buv.*
Neritopsis delphinula, *D'Orb.*
Dentalium Quenstedti, *Bla.*
Pholadidea abbreviata, *Bla.*
Arca longipunctata, *Bla.*
—— mosensis, *Buv.*
—— reticulata, *Bla.*
Lucina minuscula, *Bla.*
Astarte supracorallina, *D'Orb.*
Astarte Michaudiana, *D'Orb.*
—— ovata, *Sow.* (small).
Nucula Menkii, *Röm.*
Leda lineata, *Bla.*
Corbula Deshayesia, *Buv.*
Anatina parvula, *Et.*
Trigonia Juddiana, *Lyc.*
Thracia depressa, *Sow.*
Pholadomya æqualis, *Sow.*
Inoceramus expansus, *Bla.*
Cardium striatulum, *Sow.*
Pinna, sp.
Pecten Grenieri, *Cont.*
—— demissus, *Ph.*
—— Thurmanni, *Cont.*
Anomia Dollfusii, *Bla.*
Ostrea deltoidea, *Sow.*
—— monsbeliardensis, *Cont.*
—— gibbosa, *Les.*
Exogyra nana, *Sow.*
Terebratula Gesneri, *Et.*
Lingula ovalis, *Sow.*
Hoploparia, sp.

At Holton-Moor Station, as before mentioned, a brickyard in this region occurs with similar fossils, as far as examined—that is, those that are most common at Market Rasen, with the addition of *Pholadomya ventricosa* (Sow.). More to the south two important pits in this region are seen on the Wragby and Horncastle road, called the Baumber and Langton pits. The latter, from its stratigraphical position, must be lower in the series than the former; yet its characteristic univalve is *Rostellaria mosensis*, showing how little reliance can be placed on that shell as indicating a zone. Neither of these is so rich as that at Market Rasen; and they have, besides, been less worked.

At Baumber two rows of doggers are visible—one smaller set near the top, and another of immense ones at the base. Many of these contain *Amm. Berryeri* like those of the region above, but *Amm. serratus* is also plentiful. Blue clay, 20 feet thick, lies above these latter doggers, and in places it is really difficult to say whether the fossils or the clay compose the greater part of the bed; but the fossils are difficult to preserve and much broken. The fossils obtained here are:—

Ammonites Berryeri, *Les.*
—— serratus, *Sow.*
—— decipiens, *Sow.*
—— hector, *D'Orb.*
Astarte Michaudiana, *D'Orb.*
Arca rhomboidalis, *Cont.*
Nucula Menkii, *Röm.*
Corbula Deshaysea, *Buv.*
—— fallax, *Cont.*
Homomya compressa, *Ag.*
Ceromya orbicularis, *Röm.*
Pecten Grenieri, *Cont.*
—— arcuatus, *Sow.*
Lima ædilignensis, *Bla.*
Anomia Dollfusii, *Bla.*
Ostrea, sp.
Lingula ovalis, *Sow.*
Discina elevata, *Bla.*

At Langton less of the clay is seen before reaching the doggers; but this would seem to arise from the fact that there are many rows of doggers in the clay, and the brick-pits are excavated till the first is reached, since they always lie at the base. The doggers here are brown when exposed to the air, being more or less ferruginous. The assemblage of fossils is remarkable—*Rostellaria mosensis*, as mentioned before, being abundant, with *Nucula obliquata*, which also belongs to a higher part, yet associated with several fossils (*Serpula tetragona*, *Cyprina cyreniformis*, and *Avicula ædilignensis*) which become common in the beds below. The species are:—

Ammonites Berryeri, *Les.*
—— serratus, *Sow.*
Rostellaria mosensis, *Buv.*
Nucula Menkii, *Röm.*
—— obliquata, *Bla.*
Arca rhomboidalis, *Cont.*
Avicula ædilignensis, *Bla.*
—— dorsetensis, *Bla.*
Cyprina cyreniformis, *Bla.*
Pecten demissus, *Ph.*
Serpula tetragona, *Sow.*

A small pit on the Caistor Road, near Market Rasen, which, from its stratigraphical position, is lower than those before mentioned, seems, from its fossils, to be most comparable with that of Baumber, *i. e.* by the large *Amm. Berryeri* and abundant *Lingula ovalis*; but its more numerous Market-Rasen fossils associate it more closely with the pits there. Here are found:—

Ammonites Berryeri, *Les.*
—— cymodoce, *D'Orb.*
—— decipiens, *Sow.*
—— serratus, *Sow.*
Belemnites nitidus, *Dollf.* (young).
Cerithium forticostatum, *Bla.*
Serpula tetragona, *Sow.*
Nucula Menkii, *Röm.*
Nucula obliquata, *Bla.*
Astarte supracorallina, *D'Orb.*
—— Michaudiana, *D'Orb.*
—— pesolina, *Cont.*
Inoceramus expansus, *Bla.*
Cyprina cyreniformis, *Bla.*
Lingula ovalis, *Sow.*

The number of pits on this horizon and their wide separation seem to indicate considerable total thickness. They may be considered to form a second subzone. Exposures of beds below this level exhibit, as remarked by Mr. Judd, a well-marked difference, both lithologically and palæontologically, but still not sufficient to warrant a separation, though the difference is far more marked than anywhere else below the Upper Kimmeridge, in Lincolnshire—so much so that the first time I saw these lower beds after seeing those of Market Rasen I took them to be Oxford Clay. This was at a well-sinking on the Bishopsbridge Road, about 1½ mile east of the pit last mentioned. Here were black clays with white rotten fossils in layers, most of them being undistinguishable (apparently *Pholadomyæ*); but *Ostrea dilatata* and *Belemnites* were plentiful; and there were some reptilian remains, consisting of very compressed vertebræ and long bones. On one of these, however, were numerous *Discinæ*, which, though badly preserved, showed the fine radiating striæ of *Discina Humphresiana.* The Belemnites too were not hastate, but comparable with *B. nitidus.* However, the age was settled on discovering in a cutting, west of the Wrawby cutting before mentioned, exactly similar black clays in the same stratigraphical position, containing also *Ostrea dilatata* and *deltoidea* and abundance of *Belemnites nitidus*, associated with:—

Ammonites, sp. (? young of decipiens).
Rissoa mosensis, *Buv.*
Arca minuscula, *Cont.*
Anatina minuta, *Bla.*
Serpula tetragona, *Sow.*
Trigonia, sp. (cast, elongated).
Nucula Menkii ?, *Röm.*
Corbula Deshayesia, *Buv.*
Anomia Dollfusii, *Bla.*
Lima ædilignensis, *Bla.*

Some of these which do not occur higher up are seen again, with *Ostrea deltoidea*, at Woodhall Spa. It is plain therefore that in this locality *O. dilatata* is associated with, and almost takes the place of, that oyster.

Passing towards the south, the brickyard west of West Brankwith, near Wragby, seems to be in this region from the multitude of fragments of oysters, showing the curving round of the band of similar strata to the S.E., and the low level in which the Langton pit is dug.

To the south, again, at Hawkstead Hall (five miles south-west of Horncastle), a small pit exposes gypsiferous clays (the lower zone), with septarian and rather bituminous nodules. These contain, in abundance, a peculiar form of *Amm. serratus* (like Sowerby's original), with *Belemnites nitidus* and *Ostrea deltoidea.*

The pit at Woodhall Spa, a mile to the south, is much more fossiliferous. Some of the large doggers are almost entirely composed of *Serpula tetragona*; others contain *Avicula œdelignensis*; while the clays are full of *Ostrea deltoidea* and *Belemnites nitidus*. There are beside:—

Ammonites serratus, *Sow.*
Rissoa mosensis, *Buv.*
Cyprina cyreniforms, *Bla.*
Lima ædilignensis, *Bla.*
Arca, sp,
Thracia depressa, *Sow.*

It was from this pit probably that Sowerby's original specimens of *Serpula tetragona* came, as he mentions their filling whole blocks and being associated with *Avicula inœquivalvis* (*œdilignensis*) and *Astarte* (probably *supracorallina*), which latter species we ought therefore to add here to the list.

It is a remarkable illustration of the persistency of these regions over considerable areas, that in South Yorkshire the Kimmeridge Clay seen has an exactly similar appearance to that at Woodhall Spa and Hawkstead Hall, and contains *Amm. serratus* of the Sowerbian form and *Ostrea deltoidea* at Elloughton; and near Leavening are also blocks filled with *Serpula tetragona* and numerous *Bel. nitidus* and *Ostrea deltoidea*, associated, however, with *Amm. cordatus*. Yet this is not the lowest region of the Kimmeridge Clay in Lincolnshire; for at Worlaby are met with sandy clays with very few fossils, the fauna being reduced to *Lingula ovalis* (abundant), *Lucina*, sp., and *Amm. biplex*. From their stratigraphical position they must lie below the last described, and are probably not far above the base of the formation. The exposure here is a very satisfactory one, from its proving, by the presence of *Lingula ovalis*, that it is still in Kimmeridge Clay; and therefore, of course, the beds above must be. This series of pits, again, make another well-marked subzone, characterized, as Mr. Judd noticed, by the abundance of *Ostrea dilatata* and *Belemnites nitidus*. No *Rhynchonella inconstans*, however, is reached; indeed I have never yet found it associated with *Ammonites serratus*.

It is well known that the Coral Rag is absent from Lincolnshire, and the succeeding beds are those of Oxford Clay, which may be well seen with their characteristic fossils at Bardney and Langworthy. The different exposures of Lower Kimmeridge in Lincolnshire may be thus arranged in descending order:—

Horncastle, Hamilton Hill, Brigg, Wrawby (East).
Market Rasen, Wrawby (Middle), Holton Moor.
Caistor Road.
Baumber.
Langton.
West Wrawby, West Brankwith, Hawkstead Hall.
Woodhall Spa.
Worlaby.

It is very difficult to estimate the total thickness represented by these various horizons; but as many of the pits themselves reach a depth of 30 ft., and there are eight stages, it cannot be less than 240 ft., supposing that every portion happened to be dug into at one place or another. A more probable estimate would be obtained by supposing each of these separate exposures to occupy a separate 30 feet, which would give 450 feet; but such estimates are entirely conjectural.

Comparing now the Lower Kimmeridge of other counties with this typical development in Lincolnshire, I of course include the whole of the "Middle Kimmeridge of Filey Bay" of Mr. Judd in this division. It contains several of the characteristic fossils, with others that have not been met with in Lincolnshire, among which may especially be mentioned *Exogyra virgula*. A portion of his "Lower Kimmeridge" is also probably of this division.

I have already stated that I regard the base of the pit at Ely as Lower Kimmeridge, partly on account of its more clayey character, but chiefly from its contained fossils, especially *Ammonites serratus, A. longispinus, Arca rhomboidalis, Astarte ovata, Serpula tetragona, Avicula ædilignensis, Pecten Grenieri, Dentalium Quenstedti*, and *Lingula ovalis*. Several other fossils are collected at this pit; but as this is the only pit I have seen in Cambridgeshire, they will appear in the general list.

The great mass of the Kimmeridge Clay of the "inland counties" belongs to this lower division, which accounts for Professor Phillips saying that the upper portion is most fossiliferous—that is, the region of Market Rasen. I have not very carefully examined the clay in this range, as its fossils have been already collected and recorded, but only satisfied myself of its general accordance with the Lower Kimmeridge of Lincolnshire at Swindon and at Hartwell. The clay is far more sandy than anywhere in that county, and contains several fossils peculiar to the district. At the former place, after very little if any Upper Kimmeridge, several bands are seen in some large brick-pits now in full operation, and very fossiliferous. In the nearest but one to the railway occurs a strong band of limestone full of *Amm. biplex*, a feature not seen elsewhere; and the beds dip more than 20° to the S. The dark clay at the base of the next, in which great septarian doggers occur at the top, has many layers of compressed *Thracia depressa*, which reminds one of a similar abundance of this shell at Weymouth. Prof. Phillips mentions no fossils from the Kimmeridge Clay of Swindon in his list; nor can I find any account of them. Those that I found are the following, though there must be many more:—

Ichthyosaurus, sp.
Ammonites biplex, *Sow.*
Cerithium multiplicatum, *Bla.*
Dentalium Quenstedti, *Bla.*
Trigonia muricata, *Goldf.*
—— incurva, *Bennett.*
Astarte supracorallina, *D' Orb.*
Nucula menkii, *Röm.*
Arca mosensis, *Buv.*
Lucina substriata, *Röm.*
——? balmensis, *Cont.*
Cardium striatulum, *Sow.*
Thracia depressa, *Sow.*
Pholadomya, sp.
Perna mytiloides, *Lam.*
—— Flambarti, *Dollf.*
Modiola pallida, *Sow.*
—— semiplicata, *Buv.*
Exogyra virgula, *Desh.*
—— nana, *Sow.*
Scalpellum reticulatum, *Bla.*

To those recorded from Hartwell I have to add the following very characteristic forms:—

Corbula Deshayesia, *Buv.*
Arca mosensis, *Buv.*
—— rhomboidalis, *Cont.*
Nucula Menkii, *Röm.*
Astarte supracorallina, *D'Orb.*
Pecten Thurmanni, *Cont.*
Anomia Dollfusii, *Bla.*

The clays that were dug from the deep cutting between Wootton Bassett and Swindon exhibit the same fossils, and therefore belong to the Lower Kimmeridge, though here the passage-beds (to be presently described) were also cut through. The species belonging to this zone not mentioned by Phillips are:—

Ammonites decipiens, *Sow.*
Rissoa mosensis, *Buv.*
Corbula Deshayesia, *Buv.*
Astarte ovata, *Sow.*
—— Michaudiana, *D'Orb.*
Mactromya rugosa, *D'Orb.*
Pecten Grenieri, *Cont.*
Nucula obliquata, *Bla.*
Arca mosensis, *Buv.*
—— rustica, *Cont.*
Avicula ædilignensis, *Bla.*
Thracia depressa, *Sow.*
Ostrea solitaria, *Sow.*

Thus, though there is considerable variation in lithological characters, the fauna of this Lower Kimmeridge is everywhere fairly comparable with that of Lincolnshire. I cannot record *Amm. serratus* from personal observation; but Prof. Phillips records it from Minety under the name of *Amm. superstes.*

We come now again to the coast-section as exhibited at Ringstead Bay; and here in a short space seem to be repeated the regional features that are traced in the various Lincolnshire pits.

If we start from the east or upper end, and collect the fossils, we come first to thick masses of blue clay, with the following characteristic fossils:—

Ammonites cymodoce, *D'Orb.*
Cerithium forticostatum, *Bla.*
Astarte Michaudiana, *D'Orb.*
—— regularis, *Cont.*
Nucula Menkii, *Röm.*
Corbula Deshayesia, *Buv.*
Cardium eduliforme, *Et.*
Lingula ovalis, *Sow.*
Anatina minuta, *Bla.*
Cyprina cyreniformis, *Bla.*
Pecten Grenieri, *Cont.*
Thracia depressa, *Sow.*
Pleuromya tellina, *Ag.*
Exogyra virgula, *Desh.*
—— nana, *Sow.*
Ostrea solitaria, *Sow.*

Further east we meet with the dogger blocks of Langton, &c., with *Amm. serratus, Belemnites nitidus, Trigonia Juddiana,* and *Cardium striatulum,* then black clay, with numerous *Ostrea deltoidea,* as at Woodhall Spa, and below this the sandy beds of Worlaby, with numerous large *Lingula ovalis,* and *Amm. biplex ?, Thracia depressa,* and *Cerithium crebrum.*

This succession cannot be so well traced on the west of Weymouth, where the whole exposure consists, except quite at the base, of undistinguishable blue clays. Here *Ostrea deltoidea,* though chiefly found near the base, is scattered through the clays, and *Amm. serratus,* if present, must be very rare; it has not occurred to me in any of the doggers such as usually enclose it. Its rarity in this locality may have made Dr. Waagen call these clays Middle Kimmeridge. They contain, however, a varied suite of fossils such as are associated elsewhere with that Ammonite. There is a remarkable bed of *Thracia depressa* near the base. The fossils here obtained are:—

Plesiosaurus, sp.
Gyrodus ornatissimus, *Bla.*
Pycnodus quincuncialis, *Bla.*
Ammonites biplex, *Sow.*
—— decipiens, *Sow.*
—— Berryeri, *Les.*
Cerithium forticostatum, *Bla.*
Fusus tertius, *Bla.*
Dentalium Quenstedti, *Bla.*
Corbula Deshayesia, *Buv.*
Arca rhomboidalis, *Cont.*
Astarte supracorallina, *D' Orb.*
—— Michaudiana, *D' Orb.*
—— ovata, *Sow.*
Nucula Menkii, *Röm.*
Cardium striatulum, *Sow.*
Trigonia Juddiana, *Lyc.*
Pecten Grenieri, *Cont.*
Thracia depressa, *Sow.*
Pholadomya obliqua ?, *Ag.*
Pleuromya tellina, *Ag.*
Lima virgulina, *Cont.*
Avicula dorsetensis, *Bla.*
Exogyra virgula, *Sow.*
Ostrea deltoidea, *Sow.*
Inoceramus expansus, *Bla.*
Rhynchonella pinguis, *Röm.*
Lingula ovalis, *Sow.*
Serpula runcinata, *Sow.*

To these we might add some of the fossils recorded by Dr. Waagen, especially those of his middle region, viz. *Rostellaria nodifera* and *mosensis*, *Cardium pseudoaxinus*, *Lucina substriata*, and *Opis suprajurensis*. They appear to have been gathered at the base of his middle region, and must have been associated with many of those above.

Kimmeridge Passage-beds.

The clays just described at Weymouth pass downwards into a series of more sandy and stratified beds, with a peculiar suite of fossils, which may be best described as passage-beds, and of which this is the typical locality. They are the equivalent to part of Dollfus's "Calcaires à Trigonies" of the Cap de la Hêve, according to Dr. Waagen, who includes part of them in the Upper Calcareous Grit. They have always been called Kimmeridge Clay, or, by Damon, the Kimmeridge grit; and fossils found in them inland have always been referred to that formation. Yet it must be acknowledged that the change in the fossils as we enter these beds is very striking, and accompanied by a lithological change. With some fossils peculiar to them are associated other species, found above and below in about equal numbers. I have found no indication of such beds where the Coral Rag is absent, as in Lincolnshire; but in the presence of that formation they are everywhere developed. This would serve to attach them rather to it than to the Kimmeridge Clay. The change, no doubt, both in the character of the deposit and in the accompanying life was gradual, and certain species were specially adapted for such intermediate circumstances; and this gives us the history of the deposits. Instead, therefore, of drawing hard and fast lines, it would be well to recognize such passage-beds; and calling them after the overlying series, particularly for mapping-purposes, they will receive the above proposed title.

The following is the section as exhibited on the shore beyond Sandsfoot Castle. The thickness is only estimated by the extent of ground covered between the surface outcrops, and is probably slightly above the truth.

Section of Kimmeridge Passage-beds, Weymouth, from the top to the bottom.

Lithology.	Thickness.		Observations.
	ft.	in.	
Light-coloured clay	......		No fossils.
1. Green sandy beds	3	0	Very fossiliferous (see below).
2. Rather light-blue clay	3	0	*Exogyra nana, Ostrea deltoidea.*
3. Hard yellow limestone	0	3	
4. Soft light-blue clay	1	6	
5. Hard yellow limestone	0	2	
6. Blue clay	5	0	Indurated bands, *Ostrea deltoidea.*
7. Band of oysters	0	2	*Ostrea deltoidea, Serpula intestinalis.*
8. Blue clay	2	0	*Ostrea deltoidea.*
9. Band of small oysters	1	4	Very fossiliferous (see below).
10. Blue clay	1	4	
11. Light-yellow hard band ...	0	4	
12. Blue clay	2	6	
Ironstone band of coral rag	...		
	20	7	

No. 1 has a great variety of fossils crowded against each other; and though these are moderately large and well preserved, almost every fragment of the bed contains some. It is known to collectors as the *Trigonia*-bed, from the abundance of *T. Meriani*. The following are the fossils I have from this bed:—

Ammonites biplex, *Sow.*
—— decipiens, *Sow.*
—— Berryeri, *Les.*
—— hector, *D'Orb.*
Belemnites nitidus, *Dollf.*
—— abbreviatus, *Mill.*
Turritella minuta, *K. & D.*
Rostellaria mosensis ?, *Buv.*
Phasianella striata, *Sow.*
Littorina pulcherrima, *Dollf.*
Delphinula nassoides, *Buv.*
Chemnitzia heddingtonensis, *Sow.*
Pleurotomaria reticulata, *Sow.*
Natica eudora, *D'Orb.*
Opis suprajurensis, *Cont.*
Cardium pseudoaxinus, *Th.*
—— pesolinum, *Cont.*
Cucullæa pectinata, *Ph.*
Arca mosensis, *Buv.*
—— rhomboidalis, *Cont.*
Trigonia Meriani, *Et.*
Pholadidea compressa, *Sow.*
Perna mytiloides, *Sow.*, var.
Modiola bipartita, *Ph.*
Astarte ovata, *Sow.*
Lucina substriata, *Röm.*
—— plebeia, *Cont.*
Goniomya Monodi, *Dollf.*
Thracia depressa, *Sow.*
Pleuromya donacina, *Ag.*
—— tellina, *Ag.*
—— Voltzii, *Ag.*
Gresslya ?
Pholadomya æqualis, *Sow.*
Homomya compressa, *Ag.*
Pecten midas, *D'Orb.*
—— Quenstedti, *Bla.*
—— articulatus, *Schl.*
Perna lanceolata, *Sow.*
Gervillia, sp.
Anomia, sp.
Lima pectiniformis, *Schl.*
Ostrea deltoidea, *Sow.*
—— intricata, *Cont.*
—— monsbeliardensis, *Cont.*
—— solitaria, *Sow.*
Exogyra bruntrutana, *Thur.*
—— nana, *Sow.*
Lingula ovalis, *Sow.*
Rhynchonella inconstans, *Sow.*
Serpula intestinalis, *Ph.*
—— runcinata, *Sow.*
Vermilia, sp.
Eryma Babeaui, *Opp.*
Cidaris florigemma, *Ph.*
Trochocyathus, sp.

and this is by no means a full list. Those which have been recorded by others in addition to these will appear in the table.

The small oyster-bed No. 9 is less fossiliferous as regards species so far as ascertained. They are as follows:—

Ammonites biplex, *Sow.*
Belemnites nitidus, *Dollf.*
Turbo Julii, *Et.* ?
Nucula, sp.
Mactra tenuissima, *Cont.*
Trigonia, sp.
Pleuromya tellina, *Ag.*
—— donacina, *Ag.*
Thracia depressa, *Sow.*
Pecten midas, *D'Orb.*
—— arcuatus, *Sow.*
Pecten lens, *Sow.* ?
Avicula ædilignensis, *Bla.*
Modiola subæquiplicata, *Goldf.*
Exogyra nana, *Sow.*
—— bruntrutana, *Th.*
Ostrea deltoidea, *Sow.*
Rhynchonella inconstans, *Sow.*
Serpula intestinalis, *Ph.*
Cidaris Smithii, *Wr.*
——, sp. (spine).
Eryma Babeaui, *Opp.*

On an examination of these lists, supplemented by other recorded species, it will appear that out of 72 species found in these passage-beds, while 29 are peculiar, and 13 are common to both formations, there are 20 which pass up into true Kimmeridge Clay, and 10 which come up from below, to which latter number it is probable that some of the so-called peculiar forms really belong. It is well, however, to notice that the range upwards of Coral-Rag species is almost confined to these beds, and that true Kimmeridge Clay has but very little community of fauna with that formation.

An almost exact repetition of this series in its lithological characters occurs on the west side of Ringstead Bay, and at Osmington Mills, whence many fossils have been collected, but all of them of species included in the above lists. Prof. Phillips records many of these fossils and other Coral-Rag species from Wootton-Bassett cutting, whence I also obtained in addition *Trigonia Meriani*, *Rhynchonella inconstans*, *Ostrea solitaria*, *Arca mosensis*, *Serpula intestinalis*, and *Lima pectiniformis*. As this appears to be, in England, the home of *Rhynchonella inconstans*, which occurs in higher zones abroad, we must recognize these passage-beds by its presence at Shotover and Filey, and in Cambridgeshire.

The peculiarity and abundance of the fossils of this zone, and the easily distinguished character of the matrix, render it of considerable importance for the recognition of the junction of the two formations; and separated, as it is, from the Kimmeridge Clay proper, it is a pity it has not received a more distinct recognition, but has been mixed with a portion of the true Kimmeridge Clay to form one region by Waagen. *Amm. serratus* has never occurred to me in this zone; nor is it recorded in the same bed with *Rhynchonella inconstans* by Waagen himself, though they are associated by him as characteristic fossils of the zone. I believe they occupy in England different horizons, the latter being the most characteristic fossil of these passage-beds. *Ostrea deltoidea*, which here occurs in layers, occurs also in the Coral Rag in the same locality; and a spine of *Cidaris florigemma* was certainly *in situ* in these passage-beds. Neither of these fossils, then, can be *absolutely* characteristic.

But, with regard to community of fauna, I have been struck with the number of fossils common to the Oxford and Kimmeridge Clays, taking those of the former from published lists and figures. I have myself found *Ostrea dilatata* with its associated *Serpula intestinalis* in both; and *Avicula dorsetensis*, found in Kimmeridge at Ringstead, occurs in Oxford Clay in Lincolnshire, and *Ammonites cordatus* in the Kimmeridge of Yorkshire. *Thracia depressa* is commonly recorded from both formations; and several of the vertebrate fossils which I have received as from the Kimmeridge, though not found by me *in situ*, are figured by Prof. Phillips as from the Oxford Clay, as *Rhamphorhynchus Bucklandi*, *Ischyodus Egertoni*, *Hybodus grossiconus*. But what has struck me most is the almost exact resemblance, not to say identity, between the *Astarte carinata*, *Corbula Macneillii*, and *Arca subtetragona*, as figured by Prof. Morris * from the Kelloway Rock and Oxford Clay, near Chippenham, with the *Astarte supracorallina*, *Corbula Deshayesia*, and *Arca rhomboidalis*, which are so highly characteristic of the Kimmeridge Clay. Prof. Phillips also records *Discina latissima* from the Oxford Clay; but this perhaps requires confirmation. If all these, and others of more doubtful authority, are really common to the two formations, we are scarcely justified in separating them as Middle and Upper Oolites. In Lincolnshire they are one continuous formation, scarcely more distinct by their fossils than the two divisions of the Kimmeridge Clay; and they partake together of the thinning-out as they enter Yorkshire. But this subject requires further investigation.

Conclusions.

The Kimmeridge Clay in England is divisible into two sections, Upper and Lower, and, when preceded by the Coral Rag, possesses at the base a series of no great thickness, which we may call the Kimmeridge Passage-beds.

The Upper Kimmeridge is fairly comparable to the lower portion at least of the *Virgulian* group of foreign authors.

It consists of paper-shales, paper-slabs, bituminous shales, and cement-stones, with clays interstratified, and may reach a thickness of 650 feet and more. Its fauna is characterized by a comparative paucity of forms, but an infinity of individuals. All the great Saurian remains from near Kimmeridge belong to this portion of the series.

It is of considerable thickness in Dorsetshire and Lincolnshire, but is very inconsiderable or absent in the inland counties.

No distinct fauna comparable to that of the Middle Kimmeridge or *Pterocerian* group has yet been discovered in England, though several of the less peculiar fossils of that group are found associated with Lower Kimmeridge forms.

The Lower Kimmeridge is a mass of blue or sandy clay very little stratified, with numerous calcareous doggers. It is largely and typically developed in Lincolnshire, where it shows well-marked regions, which exhibit, however, such a gradual community of fossils, that they cannot be made the basis of subdivision, but must be con-

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* Quart. Journ. Geol. Soc. vol. vi. p. 317, 1850.

sidered local features. The whole represents the *Astartian* group of foreign geologists.

The fauna of this section will be found to have been considerably added to.

The total thickness of this section cannot well be ascertained. It has been estimated at 300 ft. to 500 ft. in Ringstead Bay, and cannot be much less than 400 ft. in Lincolnshire.

Although the greatest developments of the two sections are not known upon the same area, yet we must *add* the two thicknesses to obtain the possible total, which produces 1050 ft. exclusive of passage-beds.

The Kimmeridge Passage-beds are developed only in the presence of the Coral Rag, whose fossils ascend into them, but not to any appreciable extent above.

They are typically developed at Weymouth, where they are about 20 ft. thick.

The Oxford and Kimmeridge Clay seem to be bound together by many forms in common.

Appendix A.

Table showing the Vertical and Horizontal Distribution of all recorded Kimmeridge-clay fossils.

B, Buckinghamshire; C, Cambridgeshire; D, Dorsetshire; L, Lincolnshire; N. Norfolk; O, Oxfordshire; W, Wiltshire; Y, Yorkshire; Large letters when the species is common, small when it is rare; *, Present.

Names.	Older formations.	Passage-beds.	Lower Kim. Clay.	Upper Kim. Clay.	Portlandian.
Pterodactylus, sp.	......	......	......	d	
Gigantosaurus megalonyx, *Seeley* MS.	......	......	c ?		
Ischyrosaurus	......	......	d		
Megalosaurus Bucklandi, *Ow.*	*	......	w		
Cetiosaurus humero-cristatus, *Hulke*	......	......	d		
Plesiosaurus affinis, *Ow.*	......	......	o		
—— brachyspondylus, *Ow.*	......	......	OC		
—— brachistospondylus, *Hulke*	......	......	......	d	
—— Manselii, *Hulke*	......	......	......	d	
—— dædicomus, *Ow.*	......	......	o		
—— ellipsospondylus, *Ow.*	......	......	o		
—— plicatus, *Ph.*	......	......	o		
—— trochanterius, *Ow.*	......	......	o		
—— validus, *Ph.*	......	......	O		
—— hexagonalis, *Ph.*	......	......	o		
—— megadeirus, *Seeley, MS.*	......	......	c	d	
—— stenodeirus, *Seeley, MS.*	......	......	c		
Pliosaurus brachydeirus, *Ow.*	......	......	lOc	d	
—— gamma, *Ow.*	*	......	o		

Table (continued).

Names.	Older formations.	Passage-beds.	Lower Kim. Clay.	Upper Kim. Clay.	Portlandian.
Pliosaurus grandis, *Cw.*	*	......	o		
—— macromerus, *Ph.*	......	......	w		
—— nitidus, *Ph.*	......	......	o		
Ichthyosaurus trigonus, *Ow.*	?	......	OWl		
—— thyreospondylus, *Ow.*	......	......	Od		
—— chalarodeirus, *Seeley, MS.*	......	......	c?		
—— hygrodeirus, *Seeley, MS.*	......	......	c ?		
—— ovalis, *Ph.*	......	......	owd		
—— dilatatus, *Ph.*	......	......	O		
—— æqualis, *Ph.*	......	......	o		
—— enthekiodon, *Hulke*	......	......	......	d	
——, sp.	......	......	......	y	
Teleosaurus asthenodeirus, *Ow.*	......	......	o		
—— megarhinus, *Hulke*	......	......	......	d	
——, sp.	......	......	l		
Steneosaurus palpebrosus, *Ph.*	......	......	o		
—— Manselii, *Hulke*	......	......	......	d	
Dakosaurus lissocephalus, *Seeley*	......	......	C		
—— maximus, *Qu.*	......	......	Co		
Goniopholis, sp.	......	......	o ?		
Pelobatochelys Blakei, *Seeley*	......	d			
Enaliochelys chelonia, *Seeley*	......	......	c		
Thlattodus suchoides, *Ow.*	......	......	n ?		
Asteracanthus ornatissimus, *Ag.*	......	d	o	d?	
Ischyodon Egertoni, *Buckl.*	......	......	do		
Gyrodus coccoderma, *Eg.*	......	......	o ? d	d	
—— ornatissimus, *Blake*	......	......	D		
Pycnodus quincuncialis, *Blake*	......	......	d		
Hybodus grossiconus, *Ag.*	......	......	d		
—— acutus, *Ag.*	......	.....	o		
—— leptodus, *Ag.*	......	......	o		
Lepidotus palliatus, *Ag.*	......	......	bd		
Sphærodus gigas, *Ag.*	......	......	od		
Acrodus	......	do ?			
Strophodus reticulatus, *Ag.*	......	......	o		
Sphenonchus, sp.	......	d			
Pachycormus, sp.	......	......	......	d ? l	
Aspidorhynchus, sp.	......	......	d		
Ammonites biplex, *Sow.*	?	DW	ODWBCLY	DCLY	*
—— triplex, *Sow.*	......	......	wy	......	*
—— decipiens, *Sow.*	......	d	DWlo		
—— Berryeri, *Lesueur*	......	D	DLy		
—— yo ?, *D' Orb.*	......	......	ly		
—— hector, *D' Orb.*	......	d	l	o ?	*
—— cymodoce, *D' Orb.*	?	......	DL		
—— serratus, *Sow.*	......	......	dLyOw		
—— mutabilis, *Sow.*	......	......	ldcy		
—— longispinus, *Sow.*	......	......	c		
—— rotundus, *Sow.*	......	......	lb		
—— pectinatus, *Ph.*	......	......	......	Ld	*
—— Thurmanni, *Cont.*	......	......	......	D	
—— cordatus, *Sow.*	*	......	y		
—— eumelus, *D' Orb.*	......	......	oy ?		

Table (continued).

Names.	Older formations.	Passage-beds.	Lower Kim. Clay.	Upper Kim. Clay.	Portlandian.
Belemnites nitidus, *Dollf.*	.....	d	LYDO		
—— abbreviatus, *Mill.*	*	d	o		
—— Souichii, *D'Orb.*	......	......	......	D	
—— Trosloyanus ?, *D'Orb*	......	d ?	y		
—— excentricus, *Bl.*	......	......	o		
—— hastatus, *Montf.*	*	......	bd		
—— Owenii, *Pratt*	*	......	ob		
Coccoteuthis latipennis, *Sow.*	......	......	......	d	
Acanthoteuthis speciosa, *Münst.*	......	......	......	d	
Belemnoteuthis antiqua ? *Pratt*	?	......	......	l	
[Aptychi]	......	......	......	CLD	
Nautilus hexagonus, *Sow.*	*	d ?			
Rostellaria mosensis, *Buv.*	......	d	L		
—— nodifera, *K. & D.*	......	d ?	d		
—— rasenensis, *Blake*	......	......	l		
Alaria trifida, *Ph.*	*	d			
Nerinæa Goodhallii, *Sow.*	......	d ?			
Natica microscopica, *Cont.*	......	......	l		
—— punctulata, *Blake*	......	......	l		
—— eudora, *D'Orb*	*	d			
Cerithium crebrum, *Blake*	......	......	l		
—— multiplicatum, *Blake*	.....	......	W		
—— forticostatum, *Blake*	......	......	LD		
Turritella minuta, *K. & D.*	......	d	l		
Chemnitzia heddingtonensis, *Sow.*	*	dw			
—— inflata, *Ph.*	......	......	o ?		
—— gigantea, *Leym.*	......	w			
Littorina pulcherrima, *Dollf.*	......	d			
—— muricata, *Sow*	*	dw			
Rissoa mosensis, *Buv.*	......	......	Lw		
Tornatella secalina, *Buv.*	......	......	l		
Neritopsis delphinula, *D'Orb*	......	......	l		
Turbo Julii, *Et.*	......	d			
Phasianella striata, *Sow*	*	dw			
Delphinula nassoides, *Buv.*	......	d			
Trochus retrorsus, *Blake*	......	......	......	l	
—— excavatus, *Blake*	......	......	lw		
Pleurotomaria reticulata, *Sow.*	*	do ?	w		
—— depressa, *Ph.*	*	o ?			
——, sp.	......	d			
Dentalium Quenstedti, *Blake*	......	......	LCwd	l	
Cardium striatulum, *Sow.*	......	......	WLDBO	DLCy	
—— pseudoaxinus, *Th.*	......	d			
—— pesolinum, *Cont.*	......	d			
Lucina substriata, *Röm.*	......	d	W		
—— minuscula, *Blake*	......	......	l	DCL	
—— balmensis ?, *Cont.*	......	......	w		
—— plebeia, *Cont.*	......	d			
Cyprina cyreniformis, *Blake*	......	......	Ld		
Astarte supracorallina, *D'Orb.*	?	......	LwbD		
—— Michaudiana, *D'Orb.*	......	......	Lwd		
—— pesolina, *Cont.*	......	......	l		

Table (continued).

Names.	Older formations.	Passage-beds.	Lower Kim. Clay.	Upper Kim. Clay.	Portlandian.
Astarte ovata, *Sow.*	*	d	lWcdb	*	
—— hartwellensis, *Sow.*	......	......	B		
—— regularis, *Cont.*	......	......	d		
—— lineata, *Sow.*	......	......	? w	lD	
Opis suprajurensis, *Cont.*	?	D	d		
Myoconcha Sæmanni, *Dollf.*	......	d			
Mactra tenuissima, *Cont.*	......	d			
Pholadomya æqualis, *Sow.*	......	d	lw		
—— acuticosta, *Sow.*	......	......	lw		
—— rustica, *Ph.*	......	......	w		
—— obliqua? *Ag.*	......	......	db		
—— Protei, *Ag.*	......	......	d		
—— paucicosta, *Röm.*	......	d			
Gresslya, sp.	......	d			
Homomya compressa, *Ag.*	......	d	l		
—— gracilis?, *Ag.*	......	......	......	l	
Goniomya Monodi, *Dollf.*	......	D			
—— parvula, *Ag.*	......	d			
Ceromya orbicularis, *Röm.*	......	......	l		
—— excentrica?, *Sow.*, sp.	*	d	wby		
Pleuromya Voltzii, *Ag.*	?	Dw?			
—— tellina, *Ag.*	*	Dw	d		
—— donacina, *Ag.*	......	D			
Mactromya rugosa, *D'Orb.*	......	......	w		
Corbula Deshayesia, *Buv.*	?	......	LbWD		
—— fallax, *Cont.*	......	......	l		
Anatina minuta, *Blake*	......	......	Ld		
—— parvula, *Et.*	......	......	l		
Thracia depressa, *Sow.*	*	d	LWDOB	......	*
—— suprajurensis, *Desh.*	......	wb			
Pholadidea compressa, *Sow.*	......	D			
—— abbreviata, *Blake*	......	......	l		
Gastrochæna gracilis, *Et.*	......	d			
Trigonia Juddiana, *Lyc.*	......	......	Ld		
—— Voltzii, *Ag.*	......	d	wld		
—— irregularis, *Seeb.*	*	w?			
—— Woodwardi, *Lyc.*	......	......	wld?		
—— elongata (?), *Sow.*	......	d			
—— Pellati, *Mun.*, *Chal.*	......	......	......	dcw?	
—— incurva, *Bennett*	......	......	w	......	*
—— muricata, *Goldf.*	......	......	w		
—— Meriani, *Ag.*	......	Dw			
—— marginata (?), *Lyc.*	......	d			
Leda lineata, *Blake*	......	......	L		
Nucula Menkii, *Röm.*	......	......	LwbD		
—— obliquata, *Blake*	......	......	Lw		
Cucullæa pectinata, *Ph.*	*	d			
Arca mosensis, *Buv.*	......	d	lwb		
—— rhomboidalis, *Cont.*	?	d	lcd	d?	
—— minuscula, *Cont.*	......	......	lcd		
—— longipunctata, *Blake*	......	......	l		
—— reticulata, *Blake*	......	......	lb?		

Table (continued).

Names.	Older formations.	Passage-beds.	Lower Kim. Clay.	Upper Kim. Clay.	Portlandian.
Arca rustica, *Cont.*	......	......	w		
Modiola bipartita, *Ph.*	*	d	wby	......	*
—— subæquiplicata, *Goldf.*	......	d			
—— pallida, *Sow.*	......	......	w	......	*
—— semiplicata, *Buv.*	......	......	Wb	......	* ?
Mytilus pectinatus, *Sow.*	......	dw			
Pinna lanceolata, *Sow.*	*	d	ob	......	*
—— granulata, *Sow.*	......	d	by		
Inoceramus expansus, *Blake*	......	......	Ld		
Gervillia tetragona, *Röm.*	......	......	......	1	
—— aviculoides, *Goldf.*	......	d ?			
Perna mytiloides, *Lam.*	......	d ?	Wb	......	*
—— Flambarti, *Dollf.*	......	......	wb		
Avicula ædilignensis, *Blake*	*	d	Lcw		
—— nummulina, *Blake*	......	......	l		
—— vellicata, *Blake*	......	......	......	l	
—— dorsetensis, *Blake*	*	......	ld		
Lima rustica, *Sow.*	*	......	b		
—— ædilignensis, *Blake*	......	......	l		
—— pectiniformis, *Schl.*	*	d			
—— virgulina, *Cont.*	......	......	d		
Pecten Grenieri, *Cont.*	......	......	lcwd		
—— Thurmanni, *Cont.*	......	......	lb		
—— midas, *D' Orb.*	......	D			
—— arcuatus, *Sow.*	*	......	lb		
—— lens, *Sow.*	*	d	cb	dl	
—— nitescens, *Ph.*	......	......	lo	......	*
—— Quenstedti, *Blake*	?	D			
—— articulatus, *Schl.*	*	D			
—— distriatus, *Leym.*	......	......	b		
Hinnites fallax, *Dollf.*	......	d ?			
Anomia Dollfusii, *Blake*	......	......	ld		
Exogyra virgula, *Desh.*	......	......	DwBOY	DC	
—— nana, *Sow.*	......	D	LWDOY		
—— bruntrutana, *Th.*	......	d			
Ostrea dilatata, *Sow.*	......	......	l		
—— deltoidea, *Sow.*	......	D	LdB		
—— monsbeliardensis, *Cont.*	......	Dd	l		
—— gibbosa, *Les.*	......	......	Lb	l ?	
—— intricata, *Cont.*	......	d			
—— solitaria, *Sow.*	*	wd	d		
Terebratula Gesneri, *Et.*	......	......	l		
Rhynchonella inconstans, *Sow.*	......	DWcyO			
—— pinguis ?, *Röm.*	......	......	ld		
Discina latissima, *Sow.*	??	......	o ?	DCLoY	
—— Humphresiana, *Sow.*	......	......	b ? l		
—— elevata, *Blake*	.....	......	l		
Lingula ovalis, *Sow.*	......	d	LCDo	dlY	
Serpula tetragona, *Sow.*	......	......	LYCW		
—— intestinalis, *Ph.*	*	D	Lo	d ?	*
—— runcinata, *Sow.*	*	D	db		
Vermicularia contorta, *Blake*	......	......	c ?		
Eryma Babeaui, *Opp.*	......	d			

Table (continued).

Names.	Older formations.	Passage-beds.	Lower Kim. Clay.	Upper Kim. Clay.	Portlandian.
Hoploparia, sp.	......	......	l		
Cidaris florigemma, *Ph.*	*	d			
—— Smithii, *Wr.*	*	d			
——, sp.	......	......	d		
—— Blumenbachii, ? *Ag.*	*	......	d		
—— horrida, *Wr.*	......	......	w		
—— spinosa, *Wr.*	......	......	b		
Hemipedina Cunningtoni, *Wr.*	......	......	b		
—— Morrisii, *Wr.*	......	......	b		
Pentacrinus, sp.	......	......	l		
Trochocyathus, sp.	......	d			
Pollicipes Hausmanni, *K. & D.*	......	......	c		
Scalpellum reticulatum, *Blake*	......	......	w		
Cytheridea Ruperti, *Blake, MS.*	......	d	Dcl		
—— triangulata, *Blake, MS.*	......	.....	dc		
Cythere rectilinea, *Blake, MS.*	......	......	dl		
—— æqualis, *Blake, MS.*	......	......	dc		
—— ? spathulata, *Blake, MS.*	......	......	l		
Cytherella munita, *Blake, MS.*	......	......	Dl		
Lagena apiculata, *Rss.*	......	......	Dl		
—— clavata, *D' Orb.*	......	......	d		
Glandulina tenuis, *Born*	*	......	d		
Nodosaria radicula, *L.*	*	......	d		
—— mutabilis, *Terq.*	*	......	d		
Dentalina communis, *D' Orb.*	*	d	d		
—— jurensis, *Terq.*	*	......	l		
—— pauperata *D' Orb.*	*	......	d		
Frondicularia nodosaria, *Terq.*	*	......	l		
Orthocerina hæringense, *Gümbel.*	*	......	d		
Vaginulina badenensis, *D' Orb.*	......	......	ld		
—— striata, *D' Orb.*	......	d	c		
—— harpa, *Röm.*	......	......	Dc		
Marginulina raphanus, *L.*	*	......	d	d	
—— lata, *Corn.*	......	......	cl	d	
—— gracilis, *Corn.*	......	......	dc		
—— inæquistriata, *Terq.*	......	......	l		
Planularia reticulata, *Corn.*	*	......	Dl		
—— strigilata, *Rss.*	......	......	c		
—— Bronni, *Röm.*	*	......	d		
Cristellaria lævigata, *D' Orb.*	......	......	Dlc	d	
—— navicula, *D' Orb.*	......	......	......	d	
Flabellina rugosa, *D' Orb.*	*	d	d		
Robulina Münsteri, *Röm.*	......	D	DL		
Planulina ornata, *Röm.*	......	......	D		
Pulvinulina pulchella, *D' Orb.*	......	......	LD		
Polymorphina fusiformis, *Röm.*	*	d	d		
Textilaria gibbosa, *D' Orb.*	......	......	l		
—— agglutinans, *D' Orb.*	......	......	d	d	
Lituola nautiloidea, *D' Orb.*	*	......	ld	d	
Webbina irregularis, *D' Orb.*	*	......	d		
Quinqueloculina bermentstorfensis, *Kübler*	......	......	d		
Pinites dejectus, *Carr.*	......	......	d		

APPENDIX B.

On New and Critical Species.

GYRODUS ORNATISSIMUS, n. sp.

Beautiful vomerine and mandibular bones of Pycnodont fishes have for some time past been obtained from the clayey beds beyond Sandsfoot Castle, near Weymouth, and have been distributed in various collections, though, from the walling-up of the cliff, their supply will now probably cease. The most beautiful are some finely preserved specimens of *Gyrodus*.

The vomer has the exterior rows of teeth not much larger than the intermediate rows; but the central row is the largest—gradually, however, diminishing in size towards the front, where the central teeth are scarcely larger than those of the side rows. The centre teeth are transversely quadrangular; the inner knob is double, and the two surrounding edges are very uniformly and conspicuously puckered. The intermediate rows have perfectly circular teeth, with the same ornament. The exterior teeth are, again, quadrangular; and the outside of the first ridge of ornament is raised into a projecting knob.

Their shape and excessive ornament distinguish these from the teeth of *G. Cuvieri* (Ag.).

In the mandibles all the four series of teeth are oblique, the two larger rows being thus rhomboidal. The inner row has eight very small teeth; the intermediate row is in a very deep furrow; the middle and outside rows have the teeth approximately equal. The ornaments are as in the vomer.

These bones vary in size from 1 in. to 1½ in. in length.

Lower Kimmeridge, Weymouth.

PYCNODUS QUINCUNCIALIS, n. sp.

An incomplete vomer, showing three transversely oval, central teeth, considerably larger than any others. The outside series show in the space between the two extreme central teeth 4 on one side and 3 on the other, being arranged alternately, the outside tooth on the left side opposite the interspace between two teeth on the right. The intermediate rows are arranged quincuncially with the central row, and are longitudinally oval, but rather oblique; very minute teeth appear between each of the larger in this row.

Such an arrangement of teeth appears to be quite peculiar, and to prevent the identification of this with any described species.

Lower Kimmeridge, Weymouth.

AMMONITES CYMODOCE (D'Orb.).

This species, when old, sometimes loses all its ribs and becomes quite smooth, according to D'Orbigny. I therefore refer such a smooth form to it.

A. EUMELUS (D'Orb.).

This may be the same as Mr. Judd's *A. marantianus*?

BELEMNITES NITIDUS (Dollf.).

Under this I have included the *B. explanatus* of Phillips, which I cannot distinguish from it. As Prof. Phillips makes no allusion to Dollfus's species, I presume it must have been unknown to him.

B. TROSLOYANUS (D'Orb.).

This is inserted on the authority of Mr. Judd. I have seen no specimen that could be fairly separated from *B. nitidus*, Dollf.

B. SOUICHII (D'Orb.).

With this I identify, with some doubt, a form which differs somewhat from the type by its remarkable curvature and also the shortness of its alveolus.

Rather common at the top of the Upper Kimmeridge, Chapman's Pool.

ROSTELLARIA RASENENSIS, n. sp. Pl. XII. figs. 16, 17.

A small species, showing 8 whorls, the two sides making an angle of about 40°. The last whorl has 11 transverse ribs, most elevated at the top, gradually fading below, with a slightly backward bend, concave towards the mouth; above the ribs the surface is cut off angularly to the suture. The whole is covered by very regular minute longitudinal ribs, both above and across the transverse ones. In the last whorl but one I count 15 ribs. Canal not very long. Length $\frac{2}{3}$ inch.

When young this rather calls to mind Tertiary forms of *Fusus*, and when adult resembles the early whorls of *Pterocera suprajurensis* (Cont.), from which it differs in the shape and persistence of the transverse ribs.

Lower Kimmeridge, Market Rasen. Many examples in the Cambridge Museum.

NATICA PUNCTULATA, n. sp.

Small; angle of spire about 76°; the last whorl ornamented with numerous, regular, longitudinal, punctated striæ. Height $\frac{1}{2}$ inch.

The ornamentation of this shell distinguishes it from all other Kimmeridge *Naticæ*.

A single specimen in the Cambridge Museum, from the Lower Kimmeridge, Market Rasen.

CERITHIUM FORTICOSTATUM, n. sp. Pl. XII. fig. 13.

Whorls visible 8; angle of spire 15°; ornamentation variable, from 13 to 16 transverse ribs, rising to a point at the top, above which the surface is cut off square to the suture; but this portion is very narrow, and is waved by the influence of the ribs. The upper whorls have from 4 to 6 smaller, very regular longitudinal ribs rising upon and marking the transverse ones, which thus become knotted. The under surface of the last whorl is also marked with more longitudinal ribs. Length $\frac{2}{3}$ inch.

The variability of the transverse and longitudinal ribs is not at all connected; so that we may have one shell with 13 transverse and 4 longitudinal, and another with 16 transverse and 6 longitudinal, in which case they appear like distinct species; but the union of 16 transverse and 4 longitudinal, or of 13 and 6 respectively, warns us they are one variable species.

Goldfuss's *Cerithium costellatum* and *muricato-costatum* so exactly represent the two extreme varieties of this, that it is only their coming from different horizons from each other and from this that makes me assign a new name; if any difference is to be found, it is that *costellatum* has broader whorls, and that in *muricato-costatum* the horizontal portion below the suture is broader. *C. nodoso-costatum* (Münst.) has its spiral angle larger, making it a more inflated shell.

Very common and characteristic of Lower Kimmeridge in Lincolnshire and Dorsetshire.

Cerithium crebrum, n. sp. Pl. XII. fig. 14.

In general shape this is very similar to the last, perhaps rather more acute, but differs in the ornamentation, and is itself variable. The spaces between the whorls are more excavated; and the horizontal portion has often fine longitudinal ribs. The transverse ribs are more numerous, being 18 in number. The longitudinal ribs are *irregular*, not of equal strength, not more than four of full strength, variable in the extent to which they influence the transverse ribs, in some making almost tubercles; the top row always sharp and prominent. Length $\frac{1}{2}$ inch.

This is, no doubt, the English representative of *C. limæforme* (Röm.). Buvignier (Géol. de la Meuse, pl. xxviii. fig. 3) figures a shell under that name very like ours, but with each whorl more convex and less separated from the next; but the original, as figured by Römer, is much more distinct.

Less common than the last, in the Lower Kimmeridge of Lincolnshire.

Cerithium multiplicatum, n. sp. Pl. XII. fig. 15.

This has also a similar appearance to the last two; in fact it is a step beyond the variety of *C. forticostatum* with most longitudinal ribs. In this the transverse ribs are most elevated at the top (as in *Rostellaria rasenensis*), where they end abruptly; the longitudinal ribs are about 12 in number, very fine, and scarcely influence the transverse ones, of which there are 12; the underpart of the last whorl has stronger longitudinal ribs, with transverse ones slightly twice bent, not corresponding with those on the side. This is, no doubt, the representative of *C. septemplicatum* (Röm.); but it differs from it in having more longitudinal ribs and stronger transverse ones. Length $\frac{1}{3}$ inch.

This represents in Wiltshire, where it is common in the Lower Kimmeridge, the *C. forticostatum* of Lincolnshire.

Tornatella secalina (Buv.), 'Géol. de la Meuse,' pl. xxiii. fig. 34.

I have great doubt in referring a single specimen to this

Portlandian species. It agrees in shape and ornament exactly; but the lip (which is broken) seems to be produced anteriorly to a short canal.

Lower Kimmeridge, Market Rasen.

TROCHUS EXCAVATUS, n. sp.

Angle of spire about 30°; 5 whorls visible, surface of whorls angular, with an elevated ridge in the centre; the space between these ridges is uniformly concave, the separation of the whorls being in the centre of the concavity; the whole is ornamented with numerous narrow inconspicuous riblets with wider concave spaces between; and the upper edge of the ridges is obscurely fimbriated. Height $\frac{1}{2}$ inch.

Lower Kimmeridge, Horncastle.

A larger specimen is in the Jermyn-Street Museum, from Wootton Bassett.

TROCHUS RETRORSUS, n. sp.

Angle of spire 45°; 5 whorls visible; angular at the lower two thirds, where it is swollen, with a line of large knobs. There are also two other rows above, and one below, the four being connected by irregular low transverse risings, having a direction backwards and downwards, and giving the knobs a slightly longer axis in that direction.

Very similar to *Trochus biornatus* (Goldf.) of the Inferior Oolite, but has two rows of knobs above the large row, and a rather smaller angle of spire.

Length $\frac{1}{4}$ inch.

A single specimen from the upper Kimmeridge, Fulletby brick-yard.

DENTALIUM QUENSTEDTI, Blake. Quenstedt, 'Jura,' tab. 98. fig. 20.

Quenstedt does not give a name to the *Dentalium* figured by him, which does not appear to differ from those found in the Kimmeridge Clay generally throughout England. I therefore propose the above name in accordance with a now accepted custom.

CARDIUM STRIATULUM (Sow.).

CARDIUM PESOLINUM, Cont.; *C. lepidum*, Sauv. and Rig.

I cannot distinguish the numerous *Protocardia* that occur in all the horizons from one another, or from *C. striatulum*, although Dr. Waagen names the one in the upper beds *C. lotharingicum* (Buv). The *Cardium pesolinum* (Cont.), which Etallon considers a synonym of his *C. eduliforme*, is a much more transverse shell, and occurs at Weymouth. It is probably this that is recorded under the latter name by Dr. Waagen. Mr. Topley regards *C. lepidum* as also a variety of *C. striatulum*.

LUCINA SUBSTRIATA (Röm.).=*L. Elsgaudiæ* (Cont.).

Lucina minuscula, n. sp. Pl. XII. fig. 8.

Small, compressed, oval, $\frac{4}{5}$ as high as broad; beaks not very prominent, nearly central, slightly anterior; without ornaments beyond fine lines of growth; breadth $\frac{1}{3}$ in.

In the upper Kimmeridge in millions everywhere. A small shell from the lower Kimmeridge, which I place with this at present, is more quadrilateral, by the posterior part of the hinge being straight, meeting the hinder edge at an angle.

I have seen no figure of a similar shell. It is much more transverse than *L. minima* (Röm.).

Cyprina cyreniformis, n. sp. Pl. XII. fig. 6.

This shell, as far as can be seen, has the hinge of a *Cyprina*, but in shape it is very like a *Cyrena*. Oval, breadth $\frac{4}{3}$ of the height, inflated; beak prominent, excentric, $\frac{3}{5}$ to the front, incurved. No ornaments beyond fine striæ of growth. Breadth $\frac{2}{3}$ of an inch. Very nearly allied to *Cyprina tenuirostris* (Et.); but that is broader still, and has its beaks more prominent and excentric, and its form more triangular. It is nearer still to *Cyprina pulchella* (De Loriol), but is more eccentric and has not the anal side truncated.

Abundant at the base of the Lower Kimmeridge, Woodhall Spa and Ringstead: the specimens from the latter locality not so broad.

Astarte supracorallina (D'Orb.). 1850.

Dollfus, who has given a figure of *A. mysis* (D'Orb.), states that these two species are distinct. The numerous specimens from almost every locality where Lower Kimmeridge Clay is found, agree better with Goldfuss's figure of *A. supracorallina*. They are all striated, however, which is not a character of either. They agree in this respect with the *A. carinata* (Ph.) described by Professor Morris (Quart. Journ. Geol. Soc. vol. vi. p. 317); but the furrows are not twice the breadth of the ribs, nor equal to them, as in Goldfuss's species. The lunule, too, is not smooth. If, therefore, these shells are not *A. supracorallina*, with which on the whole they best agree, they are neither *mysis* nor *carinata*, but a new species. Being the characteristic species of the English Lower Kimmeridge, as *A. supracorallina* is of the foreign, it seems better to suppose the species variable in these small details.

This species has been found in the Subwealden boring, as we might expect.

Ceromya orbicularis (Röm.). = *C. comitatus* (Cont.).

Anatina minuta, n. sp.

Shell narrow and oval anteriorly, broad and truncated posteriorly, inferior border very gently convex, not parallel to the superior; beaks $\frac{3}{5}$ to the front, with a fold running backwards, making a small angle with the superior border; all the shell not included within this angle ornamented with concentric folds; breadth $\frac{1}{9}$ in.

This minute species is common in and characteristic of the upper zones of the Lower Kimmeridge in Dorsetshire and Lincolnshire.

Pholadidea abbreviata, n. sp. Pl.. XII. fig. 10.

Shell widely gaping anteriorly, nearly closed and pointed posteriorly, breadth $\frac{5}{3}$ the height; ornaments, three strong ribs on the anterior portion occupying about $\frac{1}{4}$ the breadth, the second the most prominent. These are succeeded by cancellated striæ on the declivity leading down to the characteristic furrow, which is very oblique, making this declivity a triangle with a broad base; posterior portion more compressed, first rising again to a strong rib or angle, and followed by a deep valley bounded on the other side by the superior border; all this portion very obscurely ornamented with cancellated striæ; breadth $\frac{3}{4}$ in.

A unique specimen from the Lower Kimmeridge, Market Rasen.

Leda lineata, n. sp. Pl. XII. fig. 12.

Shell moderately inflated, rounded in front, produced behind to a sharp point with concave sides, the apex of the point nearest to the inferior border; this border is anteriorly convex, posteriorly concave. The superior border is depressed in front; and there is a swollen line in the portion leading from the apex to the produced point. These two swollen lines enclose between them a lanceolate depression, which is transversely minutely ribbed; and there is a similar surface not so depressed, with similar ornaments, in front. The whole surface of the shell between these two areas is beautifully cancellated by equally regular and conspicuous fine transverse and concentric ribs; posterior side longest; breadth $\frac{3}{8}$ in.

Moderately common in Lower Kimmeridge at Market Rasen only.

Nucula obliquata, n. sp. Pl. XII. fig. 5.

The whole of the shell is behind the beaks, a nearly straight line leading from them to the inferior border, which is very convex; superior border nearly straight, posterior end quickly curved; the beaks are moderately prominent and approximate; shell without ornament; breadth $\frac{1}{4}$ in., $\frac{3}{2}$ the height.

Some are less oblique than others. It has scarcely the aspect of a *Nucula*, but appears to have its hinge.

Common in the insides of large Ammonites at the top of the Lower Kimmeridge, near Market Rasen, also near Wootton Bassett.

Cucullæa pectinata (Ph.).=*C. subtexata* (Et.).

Arca longipunctata, n. sp. Pl. XII. fig. 4.

Of the general shape of *A. rhomboidalis* (Cont.). The sides meet the superior border at an angle of 110°; umbones inflated, eccentric, nearly $\frac{2}{3}$ from the posterior end, marked off by a moderately prominent keel behind, posterior to which the surface is partly concave; anterior to the keel it is uniformly convex; inferior border straight or slightly convex; area between the beaks narrow, obliquely furrowed; surface covered by broad concentric flattened ribs, with subordinate longitudinal ribs, both much broader than the spaces between them, having a number of elongated pits radiating from the beaks; surface as a whole smooth in appearance; breadth $\frac{3}{4}$ in., height $\frac{1}{2}$ in.

The keel is not so strong as in *A. rhomboidalis*; and the ornaments are different.

Rare in Lower Kimmeridge, Market Rasen.

ARCA RETICULATA, n. sp. Pl. XII. fig. 11.

The sides curve to meet the hinge-line, cutting it ultimately nearly at right angles, the general direction making an angle of about 100°. The umbonal region is not bounded by a keel, but is rounded off both before and behind; a radial rising departs from below the beak, making a small angle with the posterior part of the hinge-line; inferior margin concave in the middle, corresponding to a transverse depression which reaches the umbo, dividing it into two parts; beaks about $\frac{3}{5}$ from the posterior end; space between the beaks zero; hinge-teeth those of the section *Macrodon*; ornaments fine transverse ribs becoming broader, with others intercalated, crossed by concentric striæ; breadth twice the height.

This has the general shape and ornaments of *A. æmula*, but differs in the radial rising and the division of the umbo. The division of the umbo also separates it from other similar forms.

Less rare in Lower Kimmeridge, Market Rasen.

MODIOLA SEMIPLICATA (Buv.).

I suspect that many of the so-called *Mytilus pectinatus* belong to this species. *M. pectinatus*, however is very distinct, being triangular, with a broad base, and a true *Mytilus*.

INOCERAMUS EXPANSUS, n. sp. Pl. XII. fig. 7.

Beaks very prominent; the two sides of the shell meet there at a right angle when not broken. The posterior part is expanded so as to be almost concave; when this is broken off, the inflated central part looks much more pointed. Ornament very gentle concentric ridges; length 3 in., breadth $2\frac{3}{4}$.

?=*Mytilus trapezus* (Cont.); but it is not a *Mytilus*. Very common in the Lower Kimmeridge. Market Rasen.

PERNA MYTILOIDES (Lam.).

The specimens from the Passage-beds are much broader than usual in this species, and may perhaps belong to another.

AVICULA ÆDILIGNENSIS, n. sp. Pl. XII. fig. 2.

Umbo $\frac{1}{4}$ the length of the hinge from the anterior end, which is gently convex, not reaching far beyond the hinge, posterior end very oblique, much produced, joined to the wing (which it far outreaches) by a sharp parabolic curve; wing of moderate length; ornaments delicate ribs, with a bold sweep from the umbo, with finer intermediate ribs rising at some distance from the apex, and often two still finer ribs on each side, between them and the primary ribs; breadth

$\frac{4}{3}$ of height. The other valve is smaller, and with the ribs nearly obsolete. Average breadth 1 in.

This appears to have been called *Av. inæquivalvis*; but, though it is inequivalve, it differs from that species in having much finer ribs, with the small intermediate ones, and is altogether a more delicate shell.

Generally in the Lower Kimmeridge, but chiefly at the base, especially at Woodhall-Spa pit.

Avicula nummulina, n. sp. Pl. XII. fig. 3.

Beak $\frac{1}{5}$ from the anterior end, which is strongly convex, stretching half the breadth of the hinge-line beyond it; posterior side also convex, but slightly so, meeting the hinge-line at at angle of 100°; ornaments concentric rounded ribs, and fine, numerous, regular transverse ones; the concentric ribs strongest near the umbo, gradually giving way to the others; shell excessively compressed, like a Nummulite except for the posterior angle; nearly as high as broad; average breadth 1 in.

In the upper zone of Lower Kimmeridge, near Market Rasen.

Avicula vellicata, n. sp.

Hinge-line very short. The general shape is that of an oval with the axis making an angle of 55° with the hinge, the ends of which join the oval by two tangents; umbones moderately elevated, having a pinched appearance along the axis of the oval; ornaments strong concentric bands fimbriated in the intervals by very fine radiating striæ; diam. about $\frac{3}{4}$ in.

Common in Upper Kimmeridge, Lincolnshire.

Avicula dorsetensis, n. sp.

Shape somewhat similar to the last, but with a long narrow wing added behind, which the posterior border meets in a gentle curve. It is, however, not so oblique, and more nearly round; outer surface nearly always covered by a thick coat of the matrix, which adheres to it (? from there being a strong epidermis); when clear it has faint transverse ribs.

In the Lower Kimmeridge, Ringstead; also in Lincolnshire and in the Oxford clay.

Lima ædilignensis, n. sp. Pl. XII. fig. 9.

Very oblique, almost like a short *Lithodomus*; main axis making an angle of 60° with the hinge; inflated; beaks prominent; greatest length $1\frac{1}{8}$ inch, along main axis; breadth perpendicular to this, less than $\frac{3}{4}$ inch; ornaments very fine, regular, close-set striæ, which fimbriate the concentric lines of growth.

Rare in the Lower Kimmeridge, Lincolnshire, near the base.

Pecten midas (D'Orb.).

Pecten nitescens (Phillips).

D'Orbigny's short description (Prod. vol. ii. p. 54) might answer very well for Phillips's shell; but the figure of *P. midas*, given by Dollfus (Faune Kimméridienne, pl. 14. figs. 1–3), corresponds to another form common in the Passage-beds at Weymouth, in which there are gentle radiating risings more conspicuous in one valve than the other. It is to this I have kept the name *P. midas*, using *P. nitescens* for a smooth shell from the Lower Kimmeridge, which is found in collections as *P. demissus* (Ph.).

PECTEN LENS (Sow.).

The shells so named are not in a state to be distinguished by ears &c.; but the ornament on them can in no way be distinguished from that of true Forest-marble *P. lens*.

PECTEN QUENSTEDTI, Blake.

Pecten dentatus, Quenstedt, 'Jura,' tab. 92. fig. 3 (non Sow.).

Quenstedt having wrongly identified this shell with Sowerby's, a new name is required.

ANOMIA DOLLFUSII, Blake.

Anomia, sp., Dollfus, 'Faune Kimméridienne de la Hève,' pl. 15. fig. 5.

Dollfus having refrained from naming this very distinct form, I assign his own name to it.

It is very similar to *Spondylus ovatus* and *Posidonia suprajurensis* of Contejean, but is without doubt an *Anomia*.

Rare in Lower Kimmeridge, Lincolnshire and Hartwell.

OSTREA GIBBOSA (Lesüeur), Dollfus, *l. c.* pl. 17. fig. 5.

This is the shell generally named *O. læviuscula* (Sow.); it is very common at Market Rasen and elsewhere.

RHYNCHONELLA PINGUIS (Röm.).

A doubtful identification; the ribs are obsolete near the umbones; and the shell makes a quick bend near the inferior side; it is not so "fat" as Römer's figure: but the specimens are rather imperfect.

DISCINA ELEVATA, n. sp.

It is important to distinguish this from *D. latissima* on account of their distribution. It is more oval, smaller, with the apex more elevated, and more eccentric.

Moderately common in the Lower Kimmeridge of Lincolnshire.

VERMICULARIA CONTORTA, n. sp.

Whorls in one plane, separated from each other by spaces equal to their breadth, round, without ornament.

From the Kimmeridge Clay (? Upper or Lower), Ely. In the Cambridge Museum.

SERPULA INTESTINALIS (Ph.).

S. variabilis, Sowerby, in Fitton's 'Strata below the Chalk,' tab. 23. fig. 7.

SERPULA RUNCINATA (Sow.).

S. triserrata, Sowerby, in Fitton, *l. c.* tab. 23. fig. 8.

ERYMA BABEAUI (Oppel, Pal. Mitth. tab. 10. fig. 3, p. 42).

E. pseudobabeaui (Dollf., 'Faune Kim. de la Hève,' pl. 1. figs. 1, 2).

Oppel's name was given to the claws; Dollfus's to the carapace, which he thought might belong to Oppel's claws, though none such were found. Having found carapace and claws in the same bed, though not belonging to the same animal, I presume Dollfus is correct in his surmise, and both must be called *E. Babeaui*.

In the small oyster-bed, Passage-beds, Weymouth.

SCALPELLUM RETICULATUM, n. sp. Pl. XII. fig. 1.

Only the carina known; which is moderately curved (radius $\frac{5}{8}$ in.), length $3\frac{1}{2}$ times the greatest breadth; ornaments concentric folds, which appear, under a magnifier, crossed by longitudinal striæ, especially near the apex. Length $\frac{1}{2}$ in.

A single specimen in Lower Kimmeridge, Swindon.

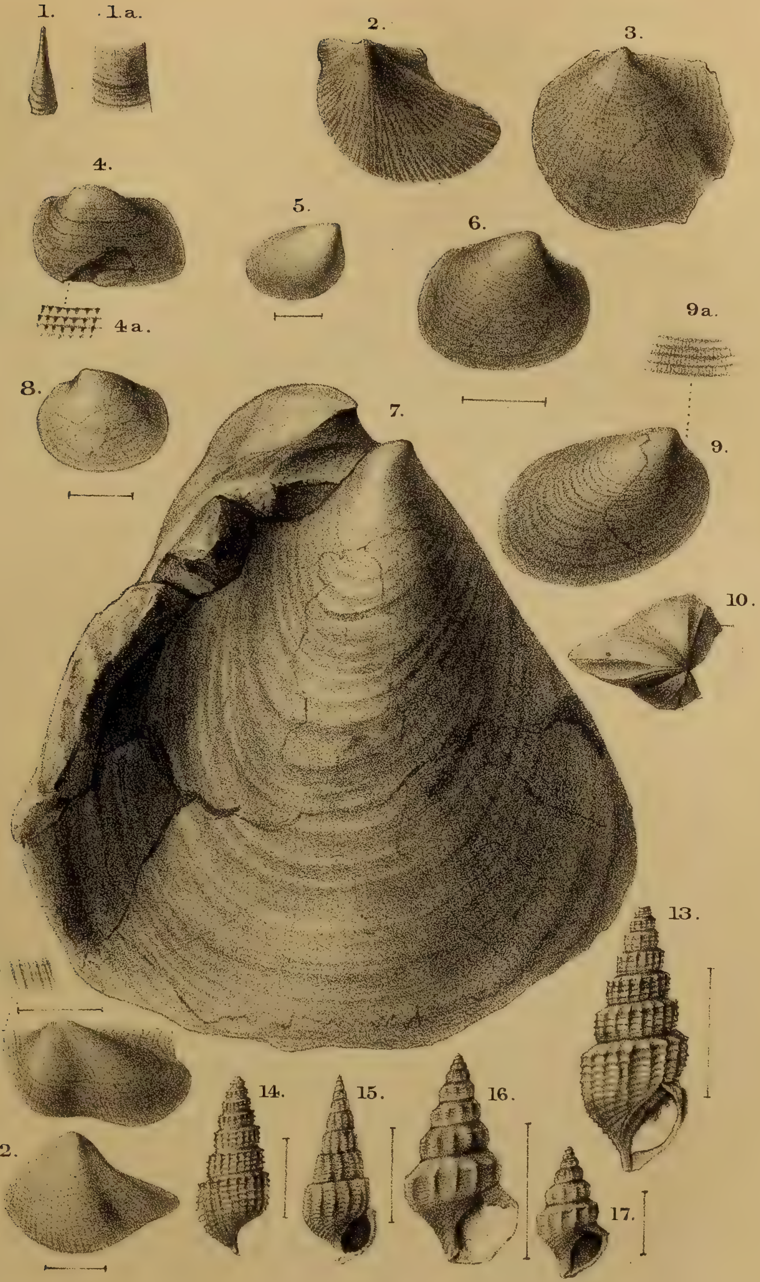
EXPLANATION OF PLATE XII.

Fossils from the Kimmeridge Clay.

Fig. 1. *Scalpellum reticulatum*: carina, nat. size. 1 *a*, portion magnified. Swindon.
2. *Avicula ædilignensis*. Woodhall Spa.
3. *Avicula nummulina*. Market Rasen.
4. *Arca longipunctata*. Market Rasen. 4 *a*, portion magnified.
5. *Nucula obliquata*. Market Rasen.
6. *Cyprina cyreniformis*. Woodhall.
7. *Inoceramus expansus*. Market Rasen.
8. *Lucina minuscula*. Market Rasen.
9. *Lima ædilignensis*. Woodhall Spa. 9 *a*, portion magnified.
10. *Pholadidea abbreviata*. Market Rasen.
11. *Arca reticulata*. Market Rasen. 11 *a*, portion magnified.
12. *Leda lineata*. Market Rasen.
13. *Cerithium forticostatum*. Market Rasen.
14. *Cerithium crebrum*. Market Rasen.
15. *Cerithium multiplicatum*. Swindon.
16, 17. *Rostellaria rasenensis*. Market Rasen.

DISCUSSION.

Prof. SEELEY complimented the author on the elaborate palæontological details which he had correlated in his paper. He noticed that the Kimmeridge Clay is thinnest in the neighbourhood of Ely, and thickens to the north, in Lincolnshire, and also southward, and that this southward thickening is concomitant with a development of sandy beds at the base and, less markedly, also at the top. As the formation is traced into France by way of Boulogne the sandy characters become more strongly marked, and eventually the deposit can no longer be recognized as a clay, though westward, at Havre,



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KIMMERIDGE-CLAY FOSSILS.

it is as much a clay as at Weymouth. He then called attention to the fact that in France there is a large curve of igneous rocks, roughly parallel to the present outcrop of the English Secondary strata, partly broken through by a mass of Palæozoic rocks, extending northward from Strasburg through Belgium, and by way of Harwich towards the Cambridgeshire area. He thought that the denudation of these deposits probably furnished the materials of the southern portion of the beds under consideration; and if so, the stratigraphical sequence becomes intelligible in this way: the Kimmeridge Grit, being sandy, resulted from an elevation of this igneous curve; and the mass of the Kimmeridge indicated that the curve was depressed so that the sand did not reach the British area; while the covering sand shows that it was again upheaved. The bottom sand is in physical continuity with the upper Calcareous Grit; and the upper sand is similarly continuous with the Portland Sand; so that he doubted whether any portion of the series is really wanting in England.

15. *Note on* PELOBATOCHELYS BLAKII *and other* VERTEBRATE FOSSILS *exhibited by the* Rev. J. F. BLAKE *in illustration of his paper on the* KIMMERIDGE CLAY. By HARRY GOVIER SEELEY, Esq., F.L.S., F.G.S., Professor of Physical Geography in Bedford College, London. (Read January 13, 1875.)

[PLATE XIII.]

THE fragments of a Chelonian carapace exhibited demonstrate the existence of a new Emydian genus, which I propose to name *Pelobatochelys*. Mr. Blake's fossil comprises the nuchal plate and first six neural plates, together with portions of the first five costal plates, of which the fourth only is complete. It is possible that the nuchal and first three neural plates belonged to one individual, and that the remaining three pertained to another animal. In the British Museum also, from Weymouth, are other evidences of the same species, which I have been able to examine. The nuchal plate is lost from this second specimen; but the first three neural plates are similarly united together, and are similarly anchylosed to the neural spines of the three corresponding vertebræ; while the third neural plate in both is excavated behind with a subcircular superficial removal of the bone extending to the margin of the adjacent costal plates; the tissue exposed is cancellous, and the hole such as might have been made by an incrusting parasite or disease, though it is perhaps just possible that a bony spine involved in the dermal covering may have been there developed.

Another specimen consists of the fourth to the eighth neural plates, with portions of the adjacent costal plates. A fourth example appears to be the pygal plate; it is impressed like the pygal plate in *Emys dorsalis*; and a fifth is one of the posterior marginal plates which shows that the distal end of the rib was received into an ovate hole. Thus nearly all the elements are available for a restoration of the carapace, which was about 16 inches long and about 14 inches wide, rather narrower from side to side in the anterior half than in the posterior half. The carapace is arched, and rises to a median ridge, being bent in the middle line of the neural plates; it begins with being gently convex from side to side over the nuchal plate, and becomes steadily more arched on passing backward as far as the plates are preserved, the median crest increasing in sharpness as in *Emys lineata*. When seen in profile the carapace is moderately convex from front to back; but the hinder margins of the vertebral scutes are elevated somewhat, as in the living *Emys lineata*, so that the curve is broken.

The imperfect ossification of the epipleural costal element, as seen in the fourth costal plate, is another character which the fossil shares with the living genus *Batagur*. The epipleuron extends but very little beyond the lateral margin of the third vertebral scute; this is a distinction from *Batagur*, in which the vertebral;scutes are narrow;

in the fossil, on the other hand, they are as broad as in *Pleurosternon,* and yet, owing to the great width of the carapace, the free end of the rib, which is flattened above and coarsely striated in length, extends beyond the epipleuron for $1\frac{3}{4}$ inch—though as this thin element divides, it shows the rib beneath, which is exposed for a length of $3\frac{1}{4}$ inches. The fifth neural plate is the longest; and from that one the neural plates become shorter to both ends of the carapace; but behind the sixth neural plate the neural arch ceases to be attached to the carapace. But the character which seems to me most typical of the fossil, and best to justify its claim to generic distinction, is the singular sagittal margins, in which the vertebral scutes meet each other.

The nuchal plate is rather more than an inch long, and joins the adjacent plates in the usual way, though the British-Museum specimen appears to show that the nuchal and first neural plates had a squamous union.

The nuchal plate is imperfectly preserved and gives no indication of its original form, its greatest transverse width being only $1\frac{3}{4}$ inch. Its anterior margin is straight, compressed, and sharp, bordered on the external surface by a slight ridge which extends backward for less than a quarter of an inch, marking what is possibly the narrow nuchal scute, which is separated from the first vertebral scute by a series of tubercles.

The next fragment, comprising the first three neural plates and portions of the six adjacent costal plates, is four inches long. The neural plates increase in thickness from before backward.

The first is of oblong form, $1\frac{3}{8}$ inch long, $\frac{3}{4}$ inch wide in the middle, and rather less at the two ends. It is convex from side to side.

The second plate is $1\frac{1}{4}$ inch long, with the anterior margin, which meets the first plate, slightly concave transversely; and the posterior margin, which meets the third neural plate, convex transversely. Owing to short lateral borders, $\frac{3}{16}$ inch long, which meet the first costal plates, this second neural plate attains its greatest transverse width of $\frac{15}{16}$ inch near the anterior end, while the sides converge posteriorly to $\frac{9}{16}$ inch.

The third neural plate is slightly worn at the hinder end; it is $1\frac{3}{8}$ inch long, joins the second pair of costal plates by anterior shoulders $\frac{3}{8}$ inch long, which widen the bone to more than an inch anteriorly, while the sides for the third pair of costal plates converge posteriorly to a width of about $\frac{9}{16}$ inch. This plate is $\frac{7}{16}$ inch thick and marked by a sharply angular median ridge. The posterior $\frac{3}{4}$ inch of this plate is excavated, as I have already remarked, but by the removal of an equal amount of bone from each side of the plate, so that its angular character is preserved.

Of the left costal plate, only narrow fragments remain; but of those on the right side the first is nearly $1\frac{1}{8}$ inch long. On the underside of the plate the head of the rib inclines a little backward. The plate is remarkably thin, and only preserved for an inch transversely. Like the adjacent first neural plate, it is crossed transversely below the middle by the posterior border of the first vertebral scute, which is thus shown to be $1\frac{3}{4}$ inch long; its width is not indicated. This boundary is an impressed line, margined behind by a row of oblong rounded tubercles, which point backward and inward, and are prolonged as faint elevated ridges over the costal and neural plates till they reach the median line of the carapace. The second costal plate is 1¼ inch long, and is preserved for a width of 2 inches. The rib is completely blended with the epipleural element, both being very thin. The articular head of the rib is concave, subquadrate, not separated from the costal plate, $\frac{3}{16}$ inch in diameter, and half an inch distant from the median line of the neural plate. The extreme thickness through the articular head is ⅜ inch.

The third costal plate is about 1⅜ inch long, and is preserved for a width of 1⅝ inch. On the underside the rib is seen as a thin convex band 1½ inch wide. This plate, like the adjacent third neural plate, is crossed just below its middle by the transverse boundary of the second vertebral scute, similarly marked by an impressed line bordered behind by a row of rounded tubercles. The second vertebral scute is therefore 2½ inches long, and at least as wide as the fragment of the second costal plate.

Mr. Blake's other specimen is 4½ inches long, and displays the 4th, 5th, and 6th neural plates. The fourth is half an inch thick, 1½ inch long, less than an inch wide in front, and ⅞ inch wide behind; it is slightly compressed in the middle. It joins the third costal plate only on the right side, by a narrow band. The costal plate is preserved on the left side.

The fifth neural plate is 1¾ inch long, more angular than the fourth; its anterior margin is undulating and widens to 1⅛ inch to form shoulders ¼ inch long for the fourth costal plates. It is somewhat constricted in the middle, and widens again at the distal end to ⅞ inch. It is crossed at less than an inch from the anterior border by the posterior border of the third vertebral scute. The fifth pair of costal plates are preserved in fragments on both sides, and show the scutal border to have been directed outward and slightly backward. As usual, it is marked by an impressed border in front; and though still bordered by tubercles behind, these are seen as the terminal teeth of serrations which resemble the teeth of a saw; and from them elevated ridges are prolonged backward and inward as from the tubercles on the anterior part of the carapace.

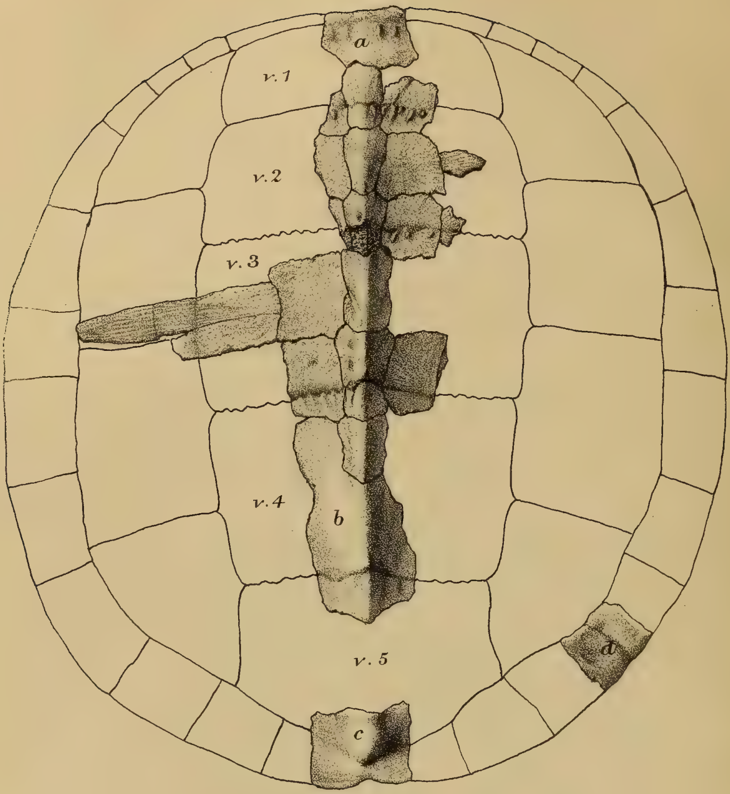
The sixth neural plate is about 1¼ inch long, ⅞ inch wide, with subparallel sides. It is nearly ⅝ inch thick, and in section is a depressed pentagon.

The fourth costal plate is 1⅝ inch long and 5¾ inch wide. The epipleural part extends transversely for 3¾ inches; but it is very thin over the rib, and in fact divides as though it were slit, so that the flat striated surface of the rib is exposed for 3½ inches.

At a distance of rather more than 4 inches from the median line of the carapace the faint impression is seen of the middle of the lateral margin of the third vertebral scute, which is about 3¼ inches long, and is thus shown to have been about 8 inches broad.

The fifth costal plates are about 1½ inch long, and are directed slightly backward like the fourth plate; but, as preserved, they only

1.



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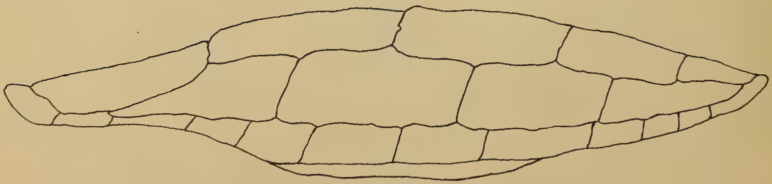

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Mintern Bros. imp.

PELOBATOCHELYS BLAKII.

extend transversely for about an inch on each side. The costal plates thicken considerably but gradually near their union with the neural plates. On the underside the ribs are very slightly elevated, though broad and clearly defined.

With this evidence Mr. Blake's materials terminate; but the British-Museum specimen shows that the seventh and eighth neural plates are crossed by the border of the fourth vertebral scute, which is 4 inches long. The anterior border rises considerably above the posterior border.

The pygal (?) plate is indented behind concavely, and impressed by a broad V-shaped scutal line, which divides the pygal scute.

This genus approaches closely to the *Palæomedusa testa* of the Lithographic Slate.

EXPLANATION OF PLATE XIII.

Fig. 1. Carapace of *Pelobatochelys Blakii*, from above, restored outline, $\frac{1}{4}$ natural size, showing the boundaries of the scutes in outline and the portions of the plates in the collections of Mr. Blake and the British Museum shaded.

- *a.* Nuchal plate.
- *b.* From the British-Museum specimen.
- *c.* Pygal plate, in the British Museum.
- *d.* Marginal plate, in the British Museum.
- V. 1–V. 5. Vertebral scutes.

Fig. 2. Side view of the same, showing the outlines of the scutes, $\frac{1}{4}$ natural size.

16. *On the* Bone-Caves *in the neighbourhood of* Castleton, Derbyshire.

By Rooke Pennington, Esq., LL.B. (Read February 10, 1875.)

(Communicated by Professor Boyd Dawkins, F.R.S., F.G.S.)

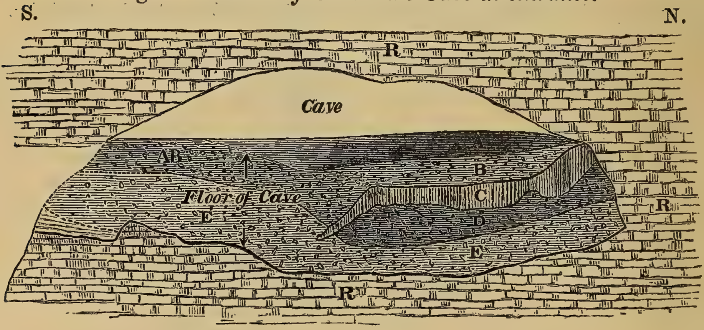
Having expended some leisure time since 1869 on the exploration of the prehistoric tumuli in the northern part of the Peak of Derbyshire, I have lately turned my attention to a few of the numerous caves and fissures existing in the Mountain-limestone district of that tract of country.

The results, together with a notice of a Staffordshire fissure (really in the same range), are contained in the following essay.

I. Prehistoric Caves.

Cave-Dale Cave.—In the romantic glen of Cave Dale, close to Castleton and just underneath the keep of the Peveril Castle, is a small cave (fig. 1). When first I knew it, it presented the appearance of a low opening, about $1\frac{1}{2}$ foot in height and 6 feet in length, so that we had to lie down flat in order to wriggle into it, and it extended about 11 feet inwards.

Fig. 1.—*Section of Cave-Dale Cave at entrance.*



A. Black earth.
B. Yellowish earth, with limestone fragments.
AB. Blackish earth, with limestone fragments.
C. Stalagmite.
D. Black earth, with limestone fragments.
E. Yellow earth, with limestone fragments.
R. Rock.

On our first visit we found inside, in the surface soil, a shilling of the time of Elizabeth. On examination of the surface of the floor, several bones were turned up, and we accordingly resolved to dig it out. This we did, with the following results.

Before we commenced work, the height from roof to floor varied from 1 foot to 4½ feet; when dug out the height from rock to rock varied from 2 feet to 6½ feet; and the depth of the deposit varied from 1 foot to 4½ feet. The cave extended right and left from the entrance, its breadth (as contrasted with its length, 11 feet) was about 14 feet.

On the south side, inside, where the deposit was not more than 2 feet thick, and outside, where it was about 4 feet thick, it consisted first of a layer of débris, consisting of blackish earth (AB) interspersed with angular fragments of limestone. The colour varied more or less; but no definite line of parting could be drawn.

Below this was a well-defined layer of yellow earth, with limestone fragments (fig. 1, E), much resembling the ordinary subsoil of this district, known locally as "fox-earth."

On the northern side, however, a different state of things appeared. First there was a superficial layer of black earth free from stone (A), and (secondly) below it a layer of yellowish earth including limestone fragments (B). These were not of the same thickness throughout; at the entrance they were together about 2 feet thick. Below them there was (thirdly) a layer of stalagmite (C), varying in thickness from 4 inches to 1 foot, and extending beneath overhanging rocks some little distance outside. This was an exceedingly well-defined bed; it had evidently in one stage of the cave's history grown over one half of its floor, whilst stalactites were being formed from above; for some had fallen and become welded into the stalagmite below. The stalagmite was exceedingly clear and white; it contained few bones, but included some fragments of limestone and numerous shells of *Helix*. Below the stalagmite was another layer of black earth (D), including limestone fragments to a greater extent than the earth above the stalagmite, and also small lumps of carbonate of lime.

Beneath this and next to the rock was the same layer of yellow earth (E) which extended beneath that part of the cave-floor which was destitute of the stalagmite.

A section of the entrance is shown in the sketch, fig. 1 (which, however, is not drawn to scale).

All the strata were more or less disturbed by the burrowing of rabbits.

The earth above the stalagmite, and that extending down to the yellow layer where no stalagmite was present, contained a most miscellaneous assortment of articles, no doubt mixed up to a great extent by the rabbits. Pieces of old-fashioned pots of a late period lay not far from bits of rude prehistoric pottery.

Of animals, determined by Mr. Boyd Dawkins, there were many bones of the Celtic short-horn (*Bos longifrons*) and goat (*Capra hircus*) both of young and old subjects; and many of them were broken, evidently purposely to get out the marrow. There were also a number of jaws and teeth, and a few bones, of hogs of various ages.

Proof of the human occupation of the cave as a dwelling-house was further afforded by the presence of a good deal of charcoal, whilst a number of human teeth seemed to point to its having at some time served as a grave.

Of animals probably not conected with man, there were many bones and teeth of the fox (*Canis vulpes*) and about as many of the badger (*Meles taxus*). Young foxes and young badgers were found. There was also a nearly perfect skull of a cat, and portions of skulls of water-rat (*Arvicola amphibia*), so common in the prehistoric barrows of this district. There was also a canine of dog, a milk-molar of red deer, a smashed bone of duck, spurs of domestic fowl, and bones of hare, with a recent skeleton of shrew.

Of implements &c., there was a tooled piece of Stag-horn, an iron spike (or what seemed to be such), 2 flints (one very good), a piece of jet, part of a bone comb, and a magnificent bronze celt of a type I believe to be unusual, bearing marks of usage, but in a splendid state of preservation. It was found in the second layer, very near the top and on the north side of the cave, just where the deposit was thickest.

The second layer contained also some rounded fragments of chert.

Below the stalagmite, and in the black earth (D) were bones and a tooth of the Celtic short-horn, part of a jaw and bones of the hog, part of a jaw and some vertebræ of red deer, a femur of wolf, and a molar of horse.

In the yellow layer (E) next the rock were more human teeth, the jaw of a hog, part of the jaw (teeth very large) and bones of red deer, and bones or teeth of goat, badger, rabbit, and cat; also a good flint implement.

Outside the cave and in the layer above the stalagmite, where it existed (the results from below the stalagmite being included in those already given) were bones of the Celtic short-horn, bones of a young dog, and bones of hogs. All these were broken.

There were also perfect bones of the fox, badger, and goat. Direct traces of man appeared in a human fibula, and a base of red-deer antler, half sawn through and then broken off; some other fragments of antlers were also present. A flint was the only other manufactured article discovered.

The cave seemed to have been from time to time occupied during a lengthened period, probably commencing in the Neolithic age, and extending into those of Bronze and Iron; whilst in historic times it has been the refuge of badgers and foxes, man now and then resorting to it for temporary purposes.

As a residence or a refuge it would be safe, sheltered, and tolerably commodious, being situated near the top of the steep sides of Cave Dale, screened from observation and the weather by a bank of earth and having a south-eastern aspect.

Gelly or Hartle Dale.—In this dale are three or four small caves or rock shelters, one to be presently mentioned.

It is one of the little glens in the Mountain-limestone to the south of Castleton.

In one of these caves, which was dug out in 1872, we found but little of the ordinary cave-earth, or of the yellowish subsoil ("fox-earth"). The floor consisted principally of blackish mould, containing a few limestone fragments and pieces of chert. It contained some bones, of which a portion were broken as though by man. They were bones of goat and pig, with those of the fox and rabbit. Two pieces of prehistoric pottery were also turned out; the ornamentation was unusually rude, even for this period, being simply punctures made in the clay, before baking, with a sharpened stick, without any regard to regularity.

II. Pleistocene Caves and Fissures.

Gelly or Hartle Dale.—Some time ago, in taking a stroll in company with Mr. Boyd Dawkins and Mr. John Tym, we entered the dale known as Gelly or Hartle Dale. Whilst examining some little caves and rock-shelters we picked up a milk-molar of a young woolly rhinoceros. It had been thrown up to the surface by rabbits burrowing in the floor of the small cave at the mouth of which it was found.

In an adjoining cavern there lay on the rock a tooth of a boar, evidently washed out of some fissure within.

The first-mentioned cave we dug out thoroughly, finding bones of rhinoceros and aurochs (*Bison priscus*), with a carpal of mammoth. There was no stalagmite present; all lay in the yellow earth mixed with angular limestone fragments, usually found in the small caves and fissures thereabouts, and which is evidently of subaerial origin. No trace of the hyæna appeared and I think there is no doubt the bones had been carried to their resting-place by water. Could the rock have been quarried away, it is highly probable that more bones would have been discovered in hidden fissures behind; that such existed was plain from the fact that the smoke of the fire lighted to boil our kettle at the mouth of a cave some 5 or 6 yards away found an exit in our cave, although no visible passage or communication existed.

Windy-Knoll Fissure.—In October 1870 I was in the Windy-Knoll quarry, in the Mountain-limestone near Castleton, when I noticed a large bone (a tibia) projecting from some of the angular débris which clothed the rock and filled the fissures.

I carried it and two or three other bones away, and showed them to Prof. Boyd Dawkins shortly after, when he determined them as belonging to the urus (*Bos primigenius*) and of Pleistocene age.

I accordingly examined the place carefully, and came to the conclusion that it was worth while to explore it. This it was impossible to do then or for long after, inasmuch as the débris was exposed in a fissure some distance up the side of the quarry, and could not be got at to any great extent without removing the rock behind which it was supported. This would have interfered with the working of the quarry, and would, in addition, have caused a great fall of earth upon broken stone lying below, to its no small detriment. However, a few bones and teeth were from time to time obtained, including those of the reindeer and aurochs, with a very fine horn-core of the latter animal.

The position of the quarry is curious. It is near the top of the Winnetts, the pass leading from the fertile Vale of Hope to the Cheshire valleys and plains, and very near to the most northern point of the Mountain-limestone of Derbyshire. Immediately to the north are the Yoredales of Mam Tor, the "Shivering Mountain." The beds dip northwards; a fault runs close to the spot. The line of division between the Mountain Limestone and the overlying rocks runs, roughly speaking, to the S.E., and S.W. of this quarry. It has been described as on the dividing-line of the east and west watersheds of the Pennine chain, and just on the western slope (Plant, Manchester Geological Society, April 28th, 1874). This is a mistake, as all the water there and for two miles to the west flows eastwards. There is immediately below, to the west, a trough-like valley, whence there is no surface outlet. All the water disappears into swallows, flows southward for a short distance underground, and is then intercepted by the channel which supplies the torrent in the Speedwell mine, which conducts it in an easterly direction to the Peak Cavern at Castleton, thence flowing into the Derwent, and so to the Trent, not into the Mersey as described.

Close to the quarry are two such water-swallows, which, however, discharge their waters into the Vale of Hope, near to the base of Tre-Cliff. And yet the situation can hardly be said to be on the eastern Pennine slope; it is, more correctly speaking, on the southern slope. The Pennine chain at its southern extremity becomes forked. Kinder Scout and its outliers constitute a range of hills than which there are none higher in England to the south. Going south from them the hills diminish, but at the same time diverge. Kinder Scout is capped by Millstone Grit; and two lines of Millstone-Grit and Yoredale hills run off from it to the S.E. and S.W. Between these two ranges, which are still of considerable height, there is exposed a less elevated range of Mountain Limestone. The highest points of their formation are lower than the Millstone-Grit heights either to north, east, or west.

By degrees all the uplands gradually diminish, until the bold heights of Edale, Castleton, Abney Moor, and Axe Edge, sink away into the wolds of South Derbyshire.

The only rivers of importance in the north of England persevering long in a southerly course are the Derbyshire Derwent, Wye, and Dove. The water-swallows of the Windy-Knoll Quarry and its vicinity discharge their streams into the Derwent; and the water does not turn eastward for any distance till the Derwent falls into the Trent, more than 40 miles from the point in question.

Observation convinced us (and subsequent exploration confirmed our conclusion) that the fissure in which the bones lay was but an offshoot of, or opening into, a sort of rock-basin lying to the north of it and behind the rocks shown in the sketch. A section of the rock would be somewhat thus:—

The surface (C, fig. 2) was composed of rubbish derived from previous working of the quarry. The rock, A, was that in which the fissure was; and the bones lay in the débris, B, at the back of the rock and filling the fissure in it.

Fig. 2.—*Section of Windy-Knoll Exploration.*

A. Rock.
B. Ossiferous loam &c.
C. Rubbish.
D. Floor of quarry.
E. Yellowish débris.

(The portion excavated is enclosed with a dotted line.)

This débris has been stated to be "drift" of glacial origin (Plant, Manchester Geological Society, Trans. April 28, 1874, pp. 2 *et seq.*). It has, however, none of the characteristics of drift; there are no foreign rocks or rounded pebbles in it; it is the ordinary loam, containing angular fragments of limestone, which is found in all hollows and fissures hereabouts; nor does it seem necessary to suppose that the Yoredales of Mam Tor have contributed to it, as no pieces of these rocks have been observed in it, and its colour is not peculiar. It is simply the subaerial débris of the Mountain-Limestone district.

About the end of April we began with the fissure, and removed the débris from it.

In May, work was systematically carried on for a fortnight, four men being constantly at work.

We first got out a quantity of the débris from behind the rock, having taken off the surface-rubbish. We then got the quarrymen to blow down the supporting rock, so as to leave exposed the face of the deposit behind. As much as possible of this was then got out and carefully examined.

The surface-rubbish contained nothing of interest; and few bones lay in the upper part of the débris. But within about 4 feet below the surface (at the point commenced with) was a most astonishing mass of animal bones, mixed in a confused manner; bones of bisons, deer, wolves, bears, and other quadrupeds lay in the greatest profusion. Near the top the loam was very damp and sticky, and the bones very rotten and difficult to get out entire. Lower down, the bones were much better-preserved. Lowest of all, near to the encircling rocks, the bones were incrusted with stalagmite, and sometimes welded together into a mass by it. This was particularly the case in the fissure and near the walls of the basin; further from the rock no such bones appeared.

This stalagmite confirms my opinion that the place was filled from the subaerial disintegration of the limestone alone, as it could only have arisen from water dripping from the rocks above and charged with carbonate of lime. The limestone rises just to the south; and thus water would flow down from it towards the "swallows" near the fissure. Near to the subjacent rock was yellowish earth (E, fig. 2), similar to that lying next to the rock all over the Mountain-Limestone district.

The period necessary for the filling-up of the basin and fissure with the débris and the included bones must have been of considerable duration. It is, of course, clear that the bones incrusted with or enclosed in stalagmite must have lain exposed for a considerable time; and the loam itself had no appearance of being washed or drifted into the fissure except very gradually, and then being rather the result of the disintegration of the rocks immediately around than from the washings of any rocks further away. All the included rocks were limestone and angular, and bore no signs of rolling; they must have fallen from time to time from the rock round the basin. Some were of large size. Certainly, if any of the fragments had been washed in, they and the loam including them must have come from the slopes to the south of the place, as there is nothing but the Yoredale series to the north.

At the same time floods may have from time to time occurred, and conveyed bones and débris into the basin.

The likeliest supposition appears to me to be that this was a swampy place, into which animals from time to time fell, or near which they died, and into which in rainy seasons their bones were washed from the neighbouring slopes.

As to the condition of the bones, some were found in the proper relative position; but most were disjointed and had evidently been disturbed since death; many were fractured, some probably by the falling of pieces of rock; others were so decayed as to be very fragmentary; and many it was impossible to extract whole.

Notwithstanding the fractures, there was no trace (except as will be specially mentioned by Mr. Dawkins) of the gnawing of hyænas or the agency of man.

Waterhouses Fissure.

There is in Staffordshire, near the road from Leek to Ashbourne, at a little village called Waterhouses, a quarry in the Mountain Limestone famous for a discovery of mammoth-remains which took place in 1864. The little river Hamps flows close to the quarry, but, just before reaching it, disappears underground, leaving its ancient bed dry save in very rainy seasons, just as the Manifold (into which it flows), the Ingleton beck in Yorkshire, and other streams do. The working of the quarry back from the river-bed exposed a fissure.

The rocks are here tilted up at an angle of about 70°; this fissure, therefore, is about parallel with the dip. It was in this fissure that the mammoth-remains referred to were found; and for some time after the discovery it remained without being further worked into. However, shortly before 1873 the rock near to it was quarried away, and more of its contents brought to light.

The fissure is one extending from the surface downwards for an unknown depth. It is about 6 feet wide, and filled with the ordinary loam, containing angular fragments of limestone. There are present also a number of quartz pebbles. To the north the Yoredale sandstones, Millstone Grit, and Coal-measures rise to a considerable height; from these the pebbles have probably been derived.

The fissure was, as mentioned above, 6 feet wide, and it appeared to me that it would narrow and close up not far from the face of the rock there exposed. A depth of 20 feet was open to view; and the bison-bones were about 17 feet below the surface, *i. e.* about 3 feet, as nearly as I can ascertain, above the horizon in which the mammoth-remains were.

There is, I think, no doubt that this bison, together with the mammoths, had fallen into the fissure when making for the Hamps for the purpose of drinking, just as sheep and cattle fall into similar pits now-a-days. And it seemed that a horse had shared the same fate; for some of the bones of that animal were also turned out. From what I saw I feel sure that the whole of the bones of the bison were present, and nearly in their proper relative position, which would not, of course, have been the case had the bones been washed in at various times.

17. *The* MAMMALIA *found at* WINDY KNOLL.

By W. BOYD DAWKINS, M.A., F.R.S., F.S.A., F.G.S., Professor of Geology and Palæontology in Owens College. (Read February 10, 1875.)

CONTENTS.

§ 1. *Introduction.*—The caves and fissures of the Mountain-limestone district of Southern Derbyshire and North Staffordshire have long been known to contain the remains of the Pleistocene mammalia; and the discovery of a tusk of Mammoth in a fissure at Doveholes, near Buxton, showed that they ranged also into Northern Derbyshire. The exploration of the caverns in the neighbourhood of Castleton extends their range into the basin of the Upper Derwent; and that of Windy Knoll in particular has yielded the greatest number of mammalian skeletons which have, so far as I know, ever been found in so small an area. The number of bones of the limbs which I have determined in Mr. Pennington's collection amounts to no less than 1183, exclusive of small fragments and splinters; while the teeth and jaws amount to 429. The number of vertebræ was too great to be classified inthe limited time at my disposal; they are to be counted by the hundred. All these were found in a space which, so far as we could estimate it, did not exceed 22 cubic feet. They belong to the following species:—

1. The Bison (*Bison priscus*).
2. The Reindeer (*Cervus tarandus*).
3. The Grisly Bear (*Ursus ferox*).
4. The Wolf (*Canis lupus*).
5. The Fox (*Canis vulpes*).
6. The Hare (*Lepus timidus*).
7. The Rabbit (*L. cuniculus*).
8. The Water-vole (*Arvicola amphibia*).

§ 2. *Bison.*—The first intimation which I had of the presence of fossil mammalia in this locality was in October 1870, when Mr. Pennington brought me a portion of a tibia and some other bones which from their size I considered to belong to the Urus (*Bos primigenius*). Viewing them now by the light of the great variations in size and form of the remains of Bison from the same locality, they are most probably to be referred to that animal, and not to the Urus.

The skulls of Bisons are, as might be expected, in a very fragmentary condition; but the more solid frontal bones form a series in which all stages of the development of the horn-cores are to be observed—from the sprout of the young calf, not more than half an inch long, to the fully-developed massive horn-core of the adult, 14 inches in length; and it is worthy of remark that the calves were present in considerable numbers.

To pass over the 32 jaws, which present no character of importance, the teeth (262 in number) may be divided into four classes, according to their age:—41 being milk-teeth of various ages; 60 young molars, fangless, or with imperfectly developed fangs; and 21 aged, fanged, and much worn.

From this it would appear that the calves, yearlings, and young

Table of Measurements of Limb-bones of Bison.

(*=Astragalar articulation. †=Metatarsal articulation.)

	Number.	Adults.	Young.		Maximum length.	Minim. circumference.	Transverse measur. of proximal articulation.	Vertical measurem. of proximal articulation.	Transverse measur. of distal articulation.	Vertical measurem. of distal articulation.	Maximum length of young shaft, without epiphysis.	Minim. circumference of young shaft.
					in.	in.	in.	in.	in.	in.	in.	in.
Humeri	80	65	15	Max.	17·3	8·2	4·5	4·0	4·2	5·0	6·0	3·8
				Min.	14·5	7·3	3·5	4·0	3·8	4·5		
Radii	62	43	19	Max.	15·1	8·0	4·4	1·7	4·1	3·0	7·0	3·0
				Min.	...	6·0	3·5	1·4	...	...		
Ulnæ	27	...	...	Max.	...	...	1·5	2·2				
				Min.	...	...	1·2	1·9				
Metacarpals	40	28	12	Max.	9·3	6·2	3·4	1·8	3·7	3·1	5·5	2·7
				Min.	8·7	4·6	2·8	1·3	2·8	2·5		
Fore phalanges(1)	32	22	10	Max.	3·2	5·2	1·8	1·5	1·6	1·4		
				Min.	2·4	4·0	1·3	1·2	1·3	1·3		
Phalanges (2) (fore & hind)	60	40	20	Max.	2·2	4·3	1·5	1·1	1·5	2·4	1·6	2·2
				Min	1·7	3·4	1·3	0·9	1 0	1 8		
Phalanges (3) (fore & hind)	35	...	...	Max.	4·2	1·5						
				Min.	2·0	0·8						
Femora	75	52	23	Max.	20·3	7·5	5·0	5·0	4·0	5·0	7·0	4·5
				Min.	...	6·4	5·0	4·5	3·5	5·0		
Patellæ	12	...	...	Max.	3·7	8·8	2·5	3·1				
				Min.	2·9	5·8	1·9	2·7				
Tibiæ	63	46	17	Max.	18·5	7·5	5·5	5·5	3·3	1·8	7·0	1·9
				Min.	18·4	7·1	5·2	5·5	3·2	1·8		
Astragali	30	...	...	Max.	3·3	7·3	2·0	1·8	2·5	2·0		
				Min.	2·9	6·2	1·8	1·4	1·8	1·4		
Calcanea	20	...	...	Max.	7·3	5·1	1·6	1·3				
				Min.	6·3	4·4	1·2	1·3				
Scaphocuboids ...	25	...	...	Max.	2·1	9·6	2·5*	1·4*	2·5†	2 5†		
				Min.	1·8	7·6	2·0	1·3	2·2	1·8		
Metatarsals	41	27	14	Max.	11·0	6·0	2·5	2·4	3·1	3·1	7·4	3·1
				Min.	10·0	4·9	2·1	2·0	2·6	2·6		
Hind phalanges(1)	30	...	...	Max.	3·1	4·5	1·3	1·5	1·5	1·8		
				Min.	2·7	3·4	1·2	1·3	1·25	1·4		

adults formed between one third and one half of the herds of Bisons which were destroyed; while the old animals were comparatively rare. The condition of many of the milk-teeth implies that some of the calves were not more than from three to five months old at the time of their death—a fact which proves that they haunted this spot in the summer and autumn, from June to November.

In order to arrive at an idea of the number of individuals represented by the teeth, I selected the last lower true and milk-molars, with the result of establishing the presence in this spot of no less than 34 animals; and even these figures, as will be seen presently from the examination of the bones, by no means represent the true number*.

Scapulæ. The shoulder-blades, as might be expected from their delicacy, were comparatively few, numbering only 35. Their glenoid articulation presented diameters ranging from 3·6 × 2·9 to 2·8 × 2·4 inches.

The variation in the size and form of the rest of the bones of the limbs may be gathered from the examination of the Table of measurements, in inches (p. 247).

The animals represented by this large series of bones and teeth cannot certainly be fewer than 40, as proved by the humeri; and they may amount to 60, since I could identify very few as having belonged to the same individual.

The bones, in the great majority of cases, had been broken in process of extraction; and very few presented marks of gnawing. Some of the femora, however, were scored with teeth-marks, feebly impressed as compared with those to be seen in the dens of Hyænas. So feeble, indeed, was the gnawing-power exercised on the bones that there were several cases of the head of the femur having been attacked without success. These marks, therefore, cannot be attributed to the powerful jaws of the Hyæna, but have been probably produced by the Bears and Wolves of which the remains were found in the same place.

Very few of the bones presented traces of disease, with the exception of the metacarpals, of which one fourth, or 10 out of 40, had been injured in front, probably by either kicks or stumbling. None of the metatarsals bore the same kind of marks, as might be expected from their being less liable to injury.

§ 3. *Reindeer.*—The remains of the Reindeer (*Cervus tarandus*) consisted of 2 skulls, 19 fragments of frontals bearing antlers, and 23 antler-fragments; and with one exception these belong to young adults. The teeth, jaws, and bones amount to 491; and of the first of these (78 in number), 21, or one quarter, were milk-molars or fangless teeth of the true molar series. The milk-molars, however, belong to older animals than those of the Bison; and among them only one third are lower molars with imperfectly developed fangs.

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* For the detailed examination and comparison of this fine series of teeth, I must refer to the Appendix to "The British Fossil Oxen" (Quart. Journ. Geol. Soc.), which I hope shortly to finish.

Some of the antlers had been gnawed, probably by Bears and Wolves; but nevertheless it must be allowed that the marks are undistinguishable from those of the Hyæna on the antlers from the caves of Kirkdale, Victoria, Wookey Hole, Brixham, and Kent's Hole.

The scapulæ are 15 in number, presenting a glenoid cavity with the maximum and minimum diameters of 1·5 × 1·3 and 1·3 × 0·9 inch.

The bones (of which I have given, in the Table, the maximum

Table of Measurements of Limb-bones of Reindeer.

	Number.		Maximum length.	Min. circumference.	Transverse measur. of proximal articulation.	Vertical measurem. of proximal articulation.	Transverse measurem. of distal articulation.	Vertical measurem. of distal articulation.	Maximum length of young shaft, without epiphysis.	Minim. circumference of young shaft.
			in.	in.	in.	in.	in.	in.		
Humeri	35	Max.	10·5	3·7	...	2·8	1·9	2·9		
		Min.	...	2·5	...	...	1·6	2·5		
Ulnæ	5	....	...	3·3	0·6	1·0				
Radii	30	Young and imperfect.								
Metacarpals ...	46	Max.	7·9	3·0	1·7	0·9	1·8	1·6		
		Min.	7·5	2·5	1·2	0·7	1·5	1·3		
		Young, with prox. epiphysis.	5·0	1·7	1·0	0·6				
Femora	52	Max.	...	2·95	2·0	2·0				
		Min.	...	...	1·75	1·6	0·9	2·0		
Tibiæ	46	Max.	12·0	...	2·0	1·5	1·25	0·5		
		Min.	...	2·5	1·5	...	1·25	0·5		
Astragali	11	Max.	1·8	3·9	1·0	0·9	1·2	1·0		
		Min.	1·8	3·6	0·9	0·6	0·1	0·9		
Calcanea	11	Adult	4·4	3·0	0·9	0.85				
		Young, without epiphyses	3 0	2·3	0·75					
Scaphocuboids	2	Max.	0·9	4·0	1·0	0·9	1·2	1·0		
		Min.	0·9	3·6	0·9	0·8	1·0	0·9		
Metatarsals ...	36	Young, without distal epiphys.	...	3·1	1·25	1·25	1·8	1·6	......	1·6
			...	1·6						
Phalanges (1)...	31	Adult, without prox. epiphys.	2·0	1·8	0·8	0·6	0·7	0·9		
			1·5	1·5	...	...	0·6	0·5		
Phalanges (2)...	13	Adult, without prox. epiphys.	1·5	1·8	0·7	0·5	0·5	1·3		
			1·0	1·3	...	...	0·4	0·6		
Phalanges (3)...	1	....	1·4	0·5	0·6					

and minimum measurements) vary considerably in size and form, especially the metacarpals, tarsals, and phalanges. These in some cases would be referred to Roe-deer, had they not formed part of this large series.

The number of individuals indicated by these remains is certainly not less than twenty, and it may range as high as thirty.

§ 4. *Grisly Bear.*—The genus *Ursus* is represented by seven jaws, eight teeth, and 46 fragmentary bones, which, with one exception, belong to adults in the full prime of life; and the number of individuals indicated is four, and perhaps five.

The five canines vary considerably in size and form, as may be seen from the following Table, in which I have inserted, for the sake of comparison, the corresponding measurements of teeth of the Cave-bear from Wookey Hole:—

		Max. length.	Length of crown.	Length of fang.	Circumference of crown.	Circumference of fang.
Ursus ferox ...	$\underline{c}|$ Windy Knoll ...	5·0	1·5	3·5	3·3	4·0
	$|\underline{c}$ "	5·0	1·5	3·5	3·3	4·0
	$\underline{c}|$ "	......	1·5	......	3·3	......
	Average	5·0	1·5	3·5	3·3	4·0
Ursus spelæus	$|\underline{c}$ Wookey Hole ...	5·5	1·5	4·0	3·3	4·0
	$\underline{c}|$ "	5·6	1·4	4·2	3·5	4·2
	$|\underline{c}$ "	5·8	1·5	4·3	3·5	4·3
	$\underline{c}|$ "	5·8	1·6	4·2	3·5	4·2
	$|\underline{c}$ "	6·0	1·7	4·3	3·6	4·3
	Average	5·54	1·55	4·2	3·48	4·2
Ursus ferox ...	$|\underline{c}$ Windy Knoll ...	......	1·3	......	3·3	
	$\underline{c}|$ "	......	1·2	......	2·4	
Ursus spelæus ...	$\underline{c}|$ Wookey Hole ...	5·6	1·4	3·2	3·4	3·7

From this examination of the canines of the upper jaw it is obvious that the species with which we are dealing falls below the standard of size of the teeth of the Cave-bear of Wookey Hole. The lower canines, on the other hand, vary considerably in size, the larger of the two approaching very nearly to that of the Cave-bear. This variation, however, is probably sexual; and the smaller of the two may be referred with considerable probability to the female, the larger to the male.

The comparison of the canines of *Ursus arctos* and *U. priscus* (*ferox*) with those of *U. spelæus* in the magnificent series in the Museum of Toulouse, as well as in those which have passed through my hands during the last fourteen years, proves that the *spelæus*-tooth is, on the whole, more massive, and especially in regard to its fang (compare fig. 2 with fig. 1). It is also generally, but not always, absolutely larger in the crown, as Professor Busk has remarked in his description of the teeth from the Brixham cave.

Fig. 1.—*Upper Canine of* Ursus priscus, *from Windy Knoll* (nat. size).

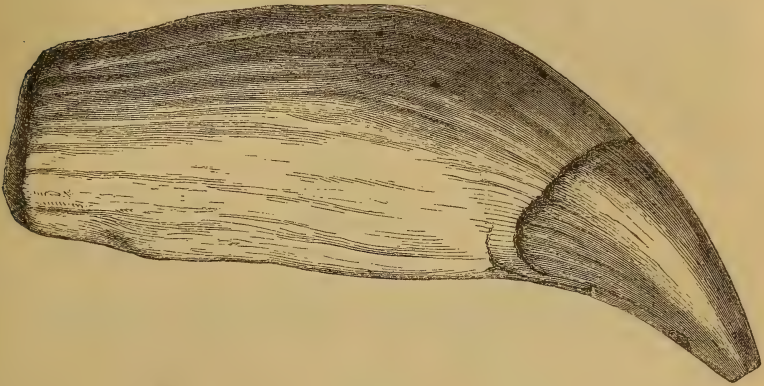


Fig. 2.—*Upper Canine of* Ursus spelæus, *from Wookey Hole* (nat. size).

In the upper canine from Windy Knoll (fig. 1) the fang is truncated; while in that figured from Wookey Hole it tapers slightly to its end.

The two lower jaws from Windy Knoll are smaller and more delicate than the massive bone in the typical *Ursus spelæus.*

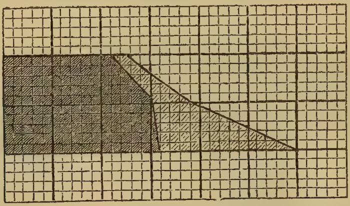
An examination of the molar series according to Professor Busk's admirable method, published in the 'Proceedings of the Royal Society,' No. 137, and in the 'Philosophical Transactions,' vol. clxiii. pl. 47, reveals at once that the animal was not the spelæan species, but closely allied to or undistinguishable from the Grisly Bear (*Ursus ferox* or *priscus*).

The upper molar series presents the following measurements:—

	Pm 4.	M 1.	M 2.
	0·55 ×0·5	0·9 ×0·7	1·45×0·78
	0·72 ×0·65	1·0 ×0·75	1·40×0·7
		1·05 ×0·8	1·70×0·9
Mean......	0·635×0·575	0·983×0·75	1·51×0·8

The mean of the measurements is represented in the odontogram of the upper dentition (fig. 3), which agrees precisely with that of *Ursus priscus* (*ferox*) published by Professor Busk (Phil. Trans. clxiii. pl. 47. fig. 9). The molar series, and especially the last true upper molar, differs from that of *Ursus spelæus* in all those points which have been enumerated in the above-cited memoir.

Fig. 3.—*Odontogram of Upper Molars of* Ursus ferox, *from Windy Knoll.*



The Ursine bones do not demand especial notice. They are forty-six in number; most of them have been broken in the process of extraction.

§ 5. *Wolf.*—The Wolf (*Canis lupus*) is represented by seven jaws, nineteen teeth, and thirty-three bones. The bones present the following measurements (p. 253).

The number of individuals represented by the remains of Wolf amounts to at least seven; and these, with the exception of one young adult, were either in their prime or approaching old age.

§ 6. *Other Animals.*—The other animals which contributed their bones to this extraordinary accumulation are the Fox, Hare, Rabbit, Water-vole, Shrew, and Bat. Their remains are rare, and present no points worthy of further notice.

Table of Measurements of Limb-bones of Wolf.

	Number.		Maximum length.	Minimum circumference.	Transverse measurement of proximal articulation.	Vertical measurement of proximal articulation.	Transverse measurement of distal articulation.	Vertical measurement of distal articulation.
			in.	in.	in.	in.	in.	in.
Humeri	7	Max.	......	2·4	......	......	1·0	1·9
		Min.	8·3	2·3	1·6	1·8	......	1·9
Ulnæ	4	......	......	......	0·6	1·0		
Radius	1	......	......	......	0·8	0·5		
Tibiæ	6	Max.	8·6	2·1	1·6	1·2	1·0	0·6
		Min.	......	......	1·9	1·1		
Astragalus	1	......	1·3	1·9	0·7	1·2	0·7	0·5
Calcaneum	1	......	2·1	1·8	0·5	0·6	0·5	

§ 7. *Remains mark Route of Migration.*—The number of individuals represented by the remains is, so far as I can estimate it, as follows:—

Bison	40–60,
Reindeer...................	20–30,
Grisly Bear	4– 5,
Wolf	7.

The herbivores are largely in excess of the carnivores; and the Bisons were far more abundant than the Reindeer during the time of the accumulation of the remains.

From the position of Windy Knoll at the head of the grand defile of the Winnetts, which would offer free passage to the mammalia in their migrations from the valley of the Derwent into the plains of Lancashire and Cheshire, it is very probable that these remains mark one of the routes by which the Bisons and Reindeer passed from the east to the west of England. They may have been accumulated at a drinking-place, as is suggested by Mr. Pennington.

The association of the carnivores with the herbivores may be satisfactorily explained on the hypothesis that they followed the Bisons and Reindeer in their migrations. With regard to the latter animals, Admiral von Wrangell gives a most graphic account of what he observed in his journey through the stony Tundra near the river Baranicha, in North-eastern Siberia *.

"I had hardly finished the observation," he writes, "when my whole attention was called to a highly interesting and, to me, a

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* 'Narrative of an Expedition to the Polar Sea in 1820–23,' edited by General Sabine [London, 1840], p. 294.

perfectly novel spectacle. Two large migrating bodies of Reindeer passed us at no great distance. They were descending the hills from the N.W., and crossing the plain on their way to the forests, where they spend the winter. Both bodies of deer extended further than the eye could reach, and formed a compact mass narrowing towards the front. They moved slowly and majestically along, their broad antlers resembling a moving wood of leafless trees. Each body was led by a deer of unusual size, which my guides assured me was always a female. One of the herds was stealthily followed by a wolf, who was apparently watching for an opportunity of seizing any one of the younger and weaker deer which might fall behind the rest; but on seeing us, he made off in another direction. The other column was followed at some distance by a large black bear, who, however, appeared only intent on digging out a mouse's nest every now and then—so much so that he took no notice of us."

The Bisons also, on the plains of Colorado, are accompanied in their migration by wolves and bears, which prey upon the stragglers.

Such a migration as this would satisfactorily account for the presence of vast quantities of the bones of Bisons and Reindeer in so limited an area as twenty-two cubic feet.

§ 8. *Migration of Bison at different season from that of Reindeer.*—A careful examination of the young teeth of the Bisons and Reindeer has further led me to conclude that these two animals migrated through the pass of the Winnetts and over Windy Knoll at different times of the year. The unworn milk-molars and the germ of milk-teeth of the former animal prove that calves not more than three or four months old formed part of the herds, which consequently must have been in that district within three or four months of calving-time, or May—in other words, in the summer and autumn. On the other hand, the milk-molars of the Reindeer were very scarce; and of them only one (the last in the series) possessed imperfect fangs. It seems, therefore, tolerably certain that they were not in the district in the summer or autumn, their calving-time (according to Sir John Richardson) being May[*]. We may therefore picture to ourselves the herds of Bison traversing the district in the summer and autumn, and the herds of Reindeer in the winter and early spring, attended by the beasts of prey (bears and wolves), as is now the case in Siberia and in Colorado.

A parallel case to this of Windy Knoll is afforded by the accumulation of bones of Reindeer, Bison, Hare, Bear, and Wolf which was discovered by Captain Luard, R.E., in 1866, in digging the foundation of a cavalry-barracks at Windsor. I found that the first two of these animals were by far the most abundant. The remains in question had most probably been derived from a ford higher up the then stream of the Thames, which offered passage to migratory bodies for many years[†].

§ 9. *The Deposit of Pleistocene Age.*—It will have been remarked that no extinct animals have been found in this deposit. Is it, then,

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[*] 'Fauna Boreali-Americana,' vol. i. p. 242.

[†] See 'Popular Science Review,' January 1868, p. 37.

to be referred to the Pleistocene age? According to Prof. Lartet it would belong to the latest stages, or those of the Bison and Reindeer. That it belongs to the Pleistocene is to me tolerably certain, because of the presence of large numbers of Reindeer and Bison, which in the succeeding period were very rare in this country. But whether it belongs to an age when the Mammoth and Woolly Rhinoceros had become extinct, seems to be an open question, since both those animals have been found in the district, and since it is extremely improbable that all the animals would migrate by the same routes. Nor is there any proof from the physical character of the superficial strata as to its relation to the Glacial period. It stands on the edge of the non-glaciated area of the eastern side of the Pennine chain of hills, where the boulder-drifts so largely developed in the west cease to be found. It is therefore also an open question as to whether it is of Pre- or of Postglacial age.

Discussion.

Mr. Evans, referring to the bronze celt mentioned by Mr. Pennington, stated that he had never seen one of a similar character, and that he thought it to be of modern workmanship. It was found, on analysis, to contain nearly 12 per cent. of zinc, which proved, at any rate, that it did not belong to the Bronze age. He said that the bones discovered were of great interest, as corresponding with those of Pleistocene age in other districts. The great quantity of Reindeer-remains was remarkable, as such numbers had not previously occurred in that part of England.

Mr. Charlesworth remarked that the difficulty connected with the finding of great numbers of mammalian remains was not confined to the case of caves. He instanced the case of Happisbro', on the Norfolk coast, where an oyster-bed was discovered in 1812 or 1813, and the fishermen brought up in their dredges immense numbers of mammalian remains. About 2000 teeth of Mammoths or Elephants, representing some 300 or 400 animals, were thus obtained in about fourteen years.

Mr. Evans observed that the accumulation in Windy-Knoll fissure might be simply due to accidents occurring to herds of Bisons and Reindeer passing that way. If the fissure remained open for about 1000 years, and 2 Bisons fell into it every 50 years from herds of 100 or more passing, the number found would easily be produced, and the survivors would probably hardly miss their lost companions.

18. *On the* Relations *of the* Cambridge Gault *and* Greensand. By A. J. Jukes-Browne, Esq., B.A., F.G.S., of the Geological Survey of England. (Read January 13, 1875.)

[Plates XIV. & XV.]

Contents.

Introduction.—I cannot do better than preface the following observations with a few words from the pen of Mr. Davidson in the 'Geological Magazine' for 1869 *. These are:—

"Some considerable difference of opinion has been expressed, not only at home, but also on the Continent, as to the real value or position of the well-known Cambridge Greensand or Phosphate-bed. Some consider it to constitute a portion of the Upper Greensand, while others would refer it to the upper portion of the Gault; and, abroad, some geologists constitute a distinct stage, for which the term *Vraconnien* is proposed.....It is a point of great importance to determine the exact age of this Cambridge bed; and in making a palæontological comparison there are several points in the case which will call for especial caution; and, as suggested by Mr. Judd, we must in the first place determine whether there are any derived fossils in the bed (so often met with in beds of phosphate nodules)."

In accordance with the above remarks the present communication has for its main objects:—

1. To determine the true position of the Cambridge bed in the Cretaceous series.
2. To trace the extent of country along which the formation may be followed.
3. To investigate the origin and age of its organic contents.

Before, however, the above-quoted paragraphs had come under my notice, the Cambridge nodule-bed had been for three or four years my especial study, which a residence in Cambridge gave me

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* "Continental Geology," Geol. Mag. vol. vi. p. 259.

great opportunities of prosecuting. I wish therefore in the first place to say a few words regarding the circumstances under which this paper came to be written.

It was in 1872 that the idea first occurred to me that the so-called Cambridge "coprolites" had not originated where they are now found, but had been derived from some part of the underlying Gault. This supposition was confirmed by subsequent conversation on the subject with the Rev. T. G. Bonney, who had, I found, for some years held the same opinion regarding their origin. His views were published in a paper read before the Geologists' Association in February, 1872, in which he gives a general review of the contents of the bed, notices the large proportion of Gault forms, and draws attention to the waterworn character of these fossils and to the eroded surface of the Gault below. This excellent paper, by its general survey of the questions connected with the Cambridge bed, was admirably fitted to clear the way for further investigations. It only remained therefore to extend the area of observation beyond the immediate neighbourhood of Cambridge, and to institute a thorough palæontological comparison between the Cambridge fauna and those of other beds between the same horizons.

With the view of assisting Mr. Bonney I at once commenced this latter undertaking in the Woodwardian Museum; the work, however, did not progress rapidly, till the presence of Mr. F. G. H. Price in Cambridge enabled me to obtain from him more accurate information regarding the Gault fauna, which he has so systematically worked out at Folkestone*. This locality I had also the advantage of visiting with Mr. Price, and of collecting from the Upper Gault nodules and fossils identical with those on our Cambridge "coprolite" heaps. My next step was to try and find the representative of this Upper Gault, with its sandy bed, in the more northern area; and, acting on information kindly given me by Mr. Whitaker, I proceeded to Cheddington, in Bucks, and thence through Bedfordshire to Hitchin.

In this traverse I was fortunate in finding the beds of which I was in search, and also succeeded in fixing the extreme south-west limit of the Cambridge nodule-bed.

Having thus acquired sufficient material for publication, I communicated the results to Mr. Bonney, who had already given the subject so much consideration, and with whom it would have afforded me much pleasure to be associated. He, however, generously waived his participation in the proposed paper, and persuaded me to publish the results of my own investigations.

In doing this I propose first to examine the physical relations of the Gault, Greensand, and Chalk in the counties of Cambridge, Bedford, and Bucks, and to compare them with the same formations in the south of England; secondly, to examine the palæontological relations between the Cambridge fauna and that of other beds between the Lower Gault and Chalk-marl (*Albien* and *Rhotomagien*), both in England and on the Continent.

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* See Quart. Journn. Geol. Soc. vol. xxx. p. 342.

Part I.—STRATIGRAPHICAL RELATIONS.

§1. *The Gault and Chalk-marl in Cambridgeshire.*—The rock of the so-called Cambridge Greensand has been well described elsewhere by Mr. Seeley[*] and by Mr. Bonney[†]. Without, therefore, entering into any detail regarding its components, it will be sufficient to state that it consists of a chalky mud or marly clay of a light green colour, except where containing, as in some places it does, such an abundance of glauconitic grains or so much Gault mud as to give the bed a darker appearance.

The "behaviour" of the bed itself, however, does not appear to have been described at sufficient length; Mr. Bonney, at p. 14 of his paper before mentioned, notices "the mode in which the deposit rests on an eroded surface of Gault, and occupies occasionally pot-holes in it, or is interrupted by shoals of Gault." Mr. Seeley, too, had previously remarked upon "the flat *irregular* surface of clay which the coprolites rest upon." Again, he says[‡], "there is nothing in the character of the stratum to suggest the time required for its deposition, or whether it occupied the beginning, the close, or the whole of the Greensand age; for too much stress must not be laid upon its *conformity* with the Chalk and its *unconformability* with the Gault, for these terms are only true when used *relatively*." (The italics are mine.)

Both observers, therefore, have noticed a line of erosion, though Mr. Seeley seems to think it of little importance. On the contrary I esteem it a fact of great significance, and shall have more to say about it in the sequel.

To those who have not seen any exposure of the Cambridge phosphate-bed, a description of what may be seen in any coprolite-pit may perhaps be acceptable. Such a vertical section shows really only two formations—Chalk-marl and Gault. The former of course varies in thickness according to the position of the pit; but usually 12 to 15 feet are shown, consisting of a greyish clayey marl (locally called "clunch") passing down into marl with green grains, at the bottom of which is the coprolite-bed. The nodules, however, are not confined to this thin layer, which is generally not more than 8 inches thick; but scattered coprolites extend upwards to a height of 3 or 4 feet above the surface of the Gault; it is to be noticed that these are chiefly small, and of a pale buff colour, while those in the seam are nearly always black; this is sometimes so marked that the foremen have spoken of the existence of a light vein and a dark vein, the latter being always the lowest.

There is perfect continuity therefore between the Phosphate-bed and the Chalk-marl; but there is no such passage into the Gault below; on the contrary, not only is there a sharp line of separation between them, but the surface of the clay is generally uneven,

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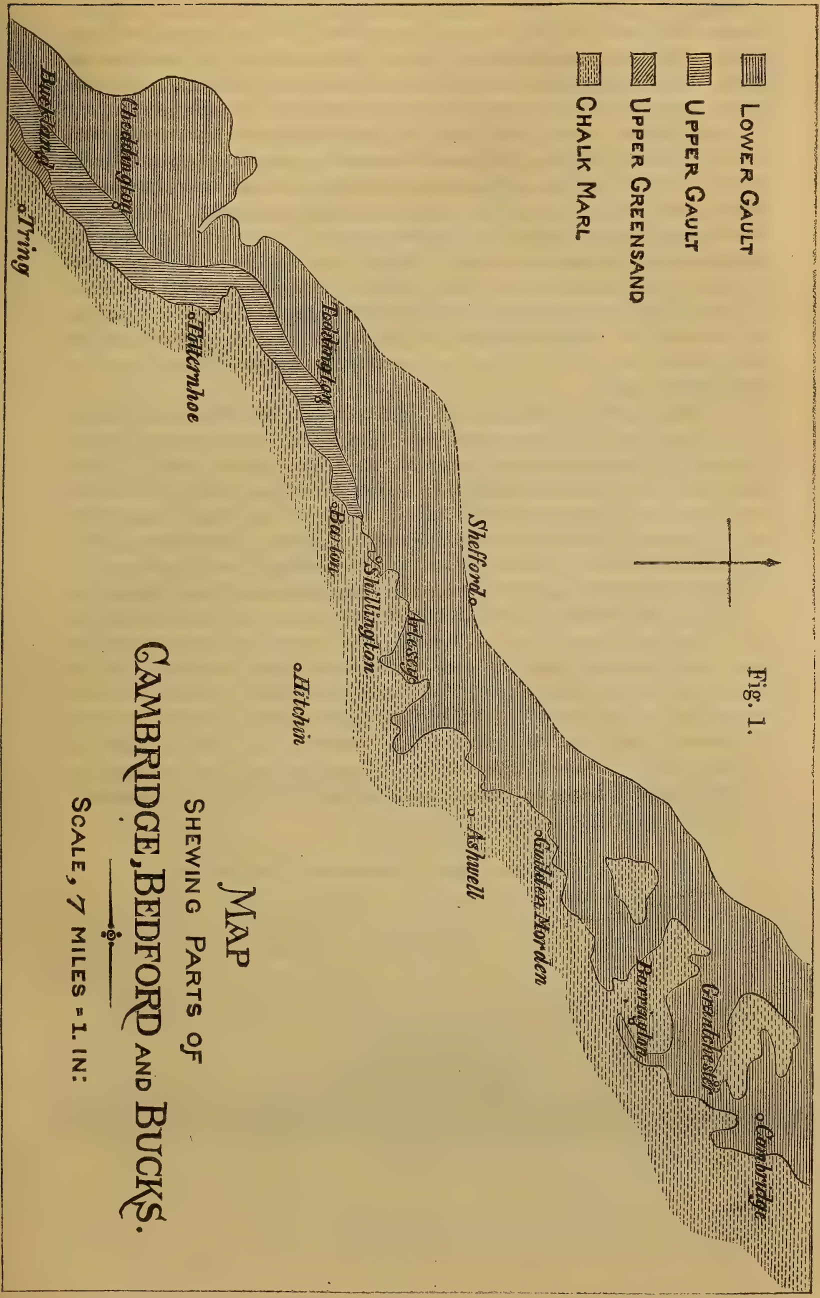
[*] "Cambridge Upper Greensand," Geol. Mag. vol. iii. p. 302.

[†] "Upper Greensand or Chloritic marl of Cambridgeshire," Proc. Geol. Assoc. vol. iii. no. 1.

[‡] Geol. Mag. vol. iii. p. 302.

Fig. 1.


Lower Gault
Upper Gault
Upper Greensand
Chalk Marl
Buckland
Cheddington
Tring
Totternhoe
Toddington
Barton
Shillington
Arlesey
Shefford
Hitchin
Ashwell
Guilden Morden
Barrington
Grantchester
Cambridge
Map
shewing parts of
Cambridge, Bedford and Bucks.
Scale, 7 miles = 1. in:

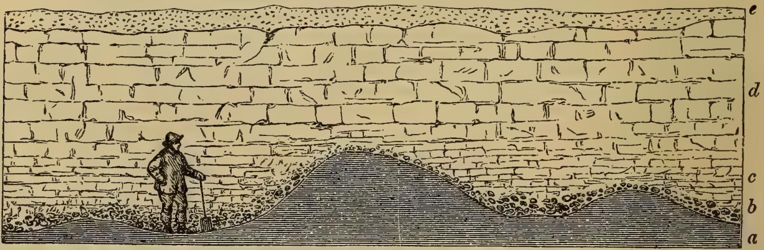
undulations and hollows being frequently visible in it. These troughs do not invariably occur, though few pits are entirely without them; they are not often very deep; but in them the nodules are generally accumulated to a depth of from 12 to 15 inches, while on the summits of the rolls and ridges the bed almost disappears.

From these facts I conclude that the Cambridge Greensand *rests on a surface of erosion*, and passes insensibly upward into true Chalk-marl. In fact, had the coprolites been pebbles of any other substance than phosphate of lime, they would no doubt have been described as forming only a pebble-bed at the base of the Chalk, and not regarded as a separate formation at all. I find that Mr. J. F. Walker takes a similar view of the case. In a letter to Mr. Davidson he says*:—"Now, if the sea-coast consisted of Gault clay which was destroyed by the sea, the nodules, bones, shells, &c. might be washed out (as the denudation of the drift-clay forms beds of gravel) and form the Cambridge bed."

In common, therefore, with Mr. Bonney and Mr. Walker I believe this unconformity (for it amounts to that) has been produced by the erosion of marine currents, probably in a shallow sea; and it flows from this as a natural consequence *that the upper beds of the Gault are now entirely wanting in Cambridgeshire*, though they must once have been well developed over this area. There is therefore a break of indefinite length between the Cambridge Gault and Greensand.

I must, however, notice another explanation which has been given of the appearances above mentioned by the Rev. O. Fisher†. He describes and figures the pockets in the Gault, but states that they only occur when the bed is near the surface, and attributes them to lateral pressure produced by land-ice. To this opinion I cannot subscribe. First of all, Mr. Fisher must allow me to correct his statement that the undulations and pockets only occur when the bed is within 3 feet of the surface. I have seen them in workings of every depth, in some places more marked than in others, but still in the deepest and shallowest pits alike.

Fig. 2.—*Section near Horningsea, Cambridge.*



a. Gault Clay. *b.* The Nodule-bed. *c.* Greenish sandy Marl. *d.* Chalk-marl. *e.* Thin Gravel and Soil.

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* See Geol. Mag. vol. vi. p. 259 (note).

† "The Coprolite-pits of Cambridgeshire," Geol. Mag. vol. viii.

One instance will suffice; and this is from a pit near Horningsea, four miles north of Cambridge. Fig. 2 (p. 260) represents the section as seen at the time I visited it. The average depth at which they were working the nodule-bed was about 12 feet; but so irregular was the surface of the Gault that in one spot the head of a man standing in the hollow was on a level with the top of the neighbouring roll or ridge, which was therefore about 5 feet high, and ran for some distance in an east and west direction.

The Chalk-marl above was in no way disturbed; and the thickness of gravel, or "trail," was very slight. It seems clear to me therefore that these and similar inequalities existed before the deposition of the Chalk-marl, and that they cannot have been produced by the pressure of ice; I think, moreover, that land-ice would hardly acquire sufficient power to make such marks over so flat a district as this part of Cambridgeshire.

Now these relations of the Gault, Coprolite-bed, and Chalk-marl continue the same throughout Cambridgeshire, from Soham, near Ely, on the north, to Guilden Morden in a southerly direction. Along this line also it is interesting to find a rapid increase in the thickness of the Gault. In the neighbourhood of Cambridge this formation, though variable in thickness, ranges only between 100 and 120 feet. At Horningsea it is only 103, at Cambridge itself from 105 to 115, at Barton and Grantchester about 120 feet. These details were given me by Mr. N. W. Johnson, of Chesterton, who has had great practical acquaintance with the Gault and Greensand of Cambridgeshire.

Information from the same source, and deduced originally from the well-sections in various coprolite-pits along the line, has enabled me to construct the following table of thicknesses presented by the Gault.

	ft.		ft.
Horningsea and Cambridge	103	to	120
Grantchester	115	„	120
Haslingfield	140	„	160
Barrington	150	„	160
Wimpole	170	„	185
Bassingbourne	150	„	175
Guilden Morden	175	„	190
Ashwell	185	„	205
Arlesey and Hitchin	204	„	214

From these figures it will be seen that, while the thickess of the Gault varies much locally, there is an increase of 100 feet between Cambridge and Arlesey. Now I consider that this is not wholly due to a westward thickening of the formation, but chiefly to the coming in of higher and higher beds of clay. In the absence of bedding or fossiliferous bands it is of course very difficult to prove this; but certain considerations, to be mentioned hereafter, render it at least very probable; and one fact may be noticed here which Mr. Johnson has observed, viz. that the clay of Ashwell and Guilden Morden is of a dull slate-colour, while that of Cambridge is more decidedly blue; this may indicate the presence of a higher horizon.

I will now proceed to describe the exposures visible in Bedford and Bucks, which derive special importance from the fact that the Cambridge coprolite-bed ceases to exist before we reach the western boundary of the former county.

§ 2. *The Gault and Chalk-marl in Bedfordshire.*—From Arlesey (which is just north of Hitchin) as far as Barton (see Map, p. 259), the Gault continues to be about 200 feet in thickness. The nodule-bed above also preserves its usual height of 8 or 9 inches; but the matrix seems to become rather more clayey in this district; the glauconite grains are equally abundant; and the pits near Shillington show the usual section in the following form:—

Sandy marl or clunch, passing down into greyish green sandy clay with coprolites.

Stiff blue Gault containing a few coprolites, which are externally of a light colour.

The surface of the clay is very uneven, and the coprolites are accumulated in the hollows. Fossils appeared to be rather scarce, *Avicula gryphæoides, Terebratula biplicata*, and teeth of *Otodus* being the most common. The bed, however, is clearly of the Cambridge type.

The next noteworthy exposure is between the villages of Barton and Sharpenhoe, about four miles south-west of Shillington. Here the section is as follows:—

	ft.
5. Greyish white marl	2
4. Greenish grey marl with a few buff-coloured coprolites	4
3. Bluish clayey marl	2
2. Bluish grey sandy clay with many fossils and coprolites = Cambridge bed	1
1. Blue clay or Gault	200

The surface of the Gault was only slightly undulating; and I was told that in one part of the pit there was a second and lower vein of coprolites about 10 inches thick, and separated from the main bed by 3 or 4 inches of stiff blue clay, but that it eventually thinned out and ran into the higher bed, thus suggesting the idea that a nodule-bed of the Gault came to the surface here.

Bed no. 2 seems to be the representative of the Cambridge Greensand; but its appearance is very different, and most of the coprolites are formed of a lighter-coloured phosphate, though some are of the usual black colour; these latter, however, have not been subjected to the same amount of rolling as those in Cambridgeshire, the small *Ostreæ* and *Plicatulæ* upon them being in much better preservation, and fine striations being visible on the latter, which I had never seen before. In some parts the bed consisted of an aggregation of small nodules cemented together into a kind of pudding-stone, which is an occasional condition of the seam in the Cambridge pits.

Some of the buff-coloured nodules, which were softer and more easily worn in the mill, probably originated in this bed or in no. 4; but others, as well as the dark coprolites, are more likely to have been washed out of the passage-beds between the Gault and Chalk described below.

The following fossils in light phosphate were picked up on the heap, amongst which the most abundant was *Avicula gryphœoides*; this could be taken from the bed itself, with the delicate shell completely preserved.

Ammonites auritus, *Sow.*
—— Studeri, *Pict.*
—— Mantelli, *Sow.*
Hamites intermedius, *Sow.*
Nautilus, sp.
Belemnites minimus, *Sow.*
Pterodactylus, sp.
Avicula gryphæoides, *Sow.*
Plicatula pectinoides, *Sow.*
—— sigillina, *Woodw.*
Ostrea vesicularis, *Sow.*
Terebratula biplicata, *Sow.*
Kingena lima, *d'Orb.*
Parkeria (flat sp.).

This is the most westerly coprolite-pit in Bedfordshire; nor is any thing seen of the Cambridge nodule-bed beyond this, though I have reason to believe that it still continues in a similar form as far as Harlington on the edge of Sheet 46, N.E.

At the next exposure, however, which is in a brick-pit at Fancott, nearly two miles S.W. of Harlington, a very different section is to be seen; this, in descending order, was:—

4. White marl or clunch, becoming grey below, and passing into no. 3 .... about	6 feet.
3. Greyish clay with iron staining in the joints	3 „
2. Bluish sandy clay with a few light-buff-coloured coprolites scattered through it	6 „
1. Dark blue clay with scattered coprolites	2 „

I got a man to dig in this bottom bed; and we turned up some coprolites and *Avicula gryphœoides*; he assured me also that about 10 feet down black coprolites became so numerous as to form a regular seam or bed. This may be the bed which cropped out in the pit at Barton; and at any rate I think it has furnished many of the coprolites found there.

The passage here is complete from top to bottom of the section, no break or discontinuity being visible anywhere; but for convenience' sake I would group the blue beds with the Gault, and the grey beds, nos. 3 and 4, with the Chalk-marl or Totternhoe Marl, as Mr. Whitaker terms it here*. They certainly cannot be called Upper Greensand.

I did not see the junction of the Chalk and Gault again for some miles, until, reaching the foot of the N.W. slope of Totternhoe Hill, I found that a well had lately been dug to a depth of 14 or 15 feet. The material thrown out was a bluish sandy clay like that in the brick-pit at Fancott; the sandiness was caused by fine gritty and micaceous spangles; no green grains were visible either here or at Fancott.

We are now within the area which has been mapped by the Geological Survey; and on referring to their Sheet 46, S.W., I was glad to find the Chalk-marl coloured as immediately succeeding the Gault to the exclusion of the Upper Greensand. I also learnt from Mr. Whitaker that he had always looked upon the Cambridge nodule-bed as forming the base of the Chalk-marl, and that he had so indi-

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* "Chalk of Buckinghamshire," Quart. Journ. Geol. Soc. vol. xxi. p. 339.

cated it in his rough copy when mapping part of the Bedfordshire sheet. In this respect, therefore, I am in entire agreement with my colleagues of the Geological Survey and their published maps.

At Eaton Bray, on the borders of Buckinghamshire, occurs the first trace of any thing like the true Upper Greensand; this is marked as an inlier on the Survey Map. The following beds are seen in the brick-yard:—

3. Pale grey marl	6 feet.
2. Greenish sandy clay	6 ,,
1. Blue sandy clay (said to be below)	—

These beds are certainly something like the top part of the Upper Greensand further west.

§ 3. *Gault and Upper Greensand of Buckinghamshire.*—Still following the same horizon, further evidences of true Upper Greensand are shortly met with—sooner, indeed, than would appear from the Survey Map; for though along the gentle slope of the hills between Eaton Bray and Buckland the junction is nowhere to be seen, yet at the outlier of West End a few feet of clayey greensand and sandy marl overlie the Gault, and clearly represent the Upper Greensand; this, therefore, would probably be discovered on the opposite escarpment if there were any cuttings, ponds, or pits to expose it.

At Buckland, near Tring (see Map, p. 259), the Upper Greensand has thoroughly set in; and nearly opposite the church is a small pond where the following beds are shown in the bank:—

	ft.	in.
3. Pale green sandy marl	2	0
2. Yellowish green marly sandstone	1	0
1. Green sandy clay	1	6

In the stream more than half a mile S.E. of Aston-Clinton church Mr. Whitaker in 1864 saw a fresh-cut section, which appeared as follows:—

3. Greensand, partly of a deep rich colour.
2. Flaggy calcareous sandstone, with occasional marly beds.
1. Greenish sandy clay (top of Gault).

From this point the Greensand gradually increases in thickness, and passes into the form under which it is well known in Oxfordshire and Berkshire, where it always consists of two members—an upper division of soft green sands and a lower stratum of hard calcareous firestone.

Mr. E. C. Davey, of Wantage, has kindly given me some particulars of the beds near that town. The soft sands are there about 30 feet thick, are fossiliferous at the top, and are immediately succeeded by Chalk-marl. The firestone contains sponges and Echinoderms; but the bed is only 6 feet thick.

The thickness of the whole formation, indeed, seems to be very variable, as the following figures will show—Risborough 60?, Cuxham 70, Didcott 120, Wantage 36, Woolstone 60, Devizes 138.

It is everywhere succeeded by the basement beds of the Chalk-marl, the Chloritic Marl being apparently absent, unless represented by the uppermost soft green sands.

§ 4. *Upper Gault in Bucks and Bedfordshire.*—We have hitherto followed the line of junction between the Gault and the overlying formations. These in lineal succession were (1) the Cambridge coprolite-bed, (2) the Chalk-marl without coprolites, (3) the Upper Greensand in Bucks. This last, therefore, the true Upper Greensand, does not pass into the Cambridge bed, but is separated from it by an interval of about ten miles, in which bare Chalk-marl comes down on the Gault. In this Chalk-marl and in the Upper Greensand the black phosphate nodules, so abundant in the Cambridge bed, are entirely wanting.

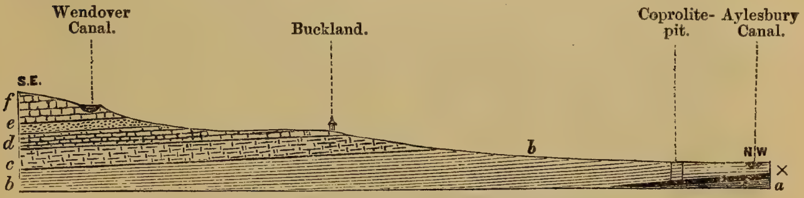
Coprolites, however, are by no means absent in Buckinghamshire; but they are only obtained from a rich bed some 40 or 50 feet down in the Gault; we will now pass, therefore, to this lower horizon. And just as we followed the Cambridge bed to the point where it disappeared, so I think it will be most convenient to trace this Gault nodule-bed back until it disappears and merges, as I believe, into the Cambridge deposit of nodules.

Starting, then, down the road which leads N.W. from Buckland, and proceeding about a mile beyond the junction of Gault and Greensand, a coprolite-pit is seen near the canal running between Buckland and Puttenham; and in it the following interesting section was shown:—

	ft.	in.
3. Whitish marly clay, looking at a distance very like Chalk-marl, but containing much "race" and a few light-coloured phosphatic nodules	8	0
2. Coprolite-bed, the upper part a grey sandy clay full of green grains and coprolites, the lower part a stiff dark green sand with rolled black nodules in abundance	1	6
1. Stiff, nearly black clay formed the bottom of the pit, apparently unfossiliferous.		

Throwing the information obtained near Buckland and Aston Clinton into the form of a diagrammatic section along a line from the Chalk escarpment through the village of Buckland to this copro-

Fig. 3.—*Diagram Section from the Chalk escarpment through Buckland to the Aylesbury Canal.* (Horizontal scale 2 inches to 1 mile.)



Gault.
- *a.* Stiff dark Gault.
- ×. Sandy marl, coprolite-bed.
- *b.* White marly clay.
- *c.* Bluish sandy clay.

Upper Green-sand.
- *d.* Flaggy calcareous sandstone with marly bands.
- *e.* Dark-green sands.
- *f.* Chalk-marl.

lite-pit, it would appear to be as in fig. 3, though I had no means of ascertaining the relative thickness of the strata represented.

From the upper part of bed 2 in the above pit-section I extracted the following fossils in an unphosphatized condition, which are quite sufficient to show that the stratum belongs to the division of the Upper Gault.

Plicatula pectinoides, *Sow.* (common).
Avicula gryphæoides, *Sow.*
Pecten orbicularis, *Sow.*
Lima globosa, *Sow.*
Ammonites rostratus, *Sow.* (small).

On the heap there was a paucity of fossils, with the exception of *Plicatula pectinoides*, which was common. The smaller nodules were very like those of Cambridge; but the larger ones presented a curious appearance, being evidently phosphatic septarian stones, hollow in the middle, and split up by contraction-cracks, which contained carbonate of lime. When struck they fell into numerous small cubical pieces. These nodules were a difficulty to me at first, until I had broken up several, and saw that the débris were exactly like the little angular fragments so common in the Cambridge bed and often bearing small *Plicatulæ* and *Ostreæ*. A very little rolling would suffice to break up these hollow nodules; and thus the apparent absence of these forms in Cambridgeshire is satisfactorily explained, while the quantity of coprolitic débris there existing is likewise accounted for.

On the other side of the canal, near the village of Puttenham, another pit has been opened showing the same succession. Here the men were at work; and I obtained from the foreman the following fossils in black phosphate:—

Ichthyosaurus campylodon, *Carter.*
Saurocephalus lanciformis, *Harlan.*
Otodus appendiculatus, *Ag.*
Ammonites rostratus, *Sow.*
—— splendens, *Sow.*
—— auritus?, *Sow.*
—— Raulinianus, *D'Orb.*
—— cratus, *Seeley.*
Belemnites minimus, *Sow.*
Solarium ornatum, *Sow.*
Hinnites trilinearis, *Seeley.*
Plicatula pectinoides, *Sow.*
—— sigillina, *Woodw.*
Spondylus gibbosus, *D'Orb.*
Lima elongata, *Sow.*
Avicula gryphæoides, *Sow.*
Terebratula biplicata, *Sow.*
Serpula articulata, *Sow.*
Ventriculites quincuncialis, *T. Smith.*
Trochocyathus angulatus, *Duncan.*

Mr. Sollas, to whom I showed the few "coprolites" I was able to carry away from the heap, recognized among them one or two Cambridge forms, as well as two specimens of *Ventriculites quincuncialis.* This is, I believe, the first time Ventriculites have been obtained from undoubted Gault.

The nodule-bed does not here rest upon a level surface, but undulates up and down, so as to remind one of the behaviour of the Cambridge bed; there was, however, this essential difference—that the nodules were never accumulated in the hollows. The foreman of the works fully appreciated this fact, which unfortunately was not to his advantage, since the deeper working in the hollows did not here repay him by a more abundant harvest of nodules, as it would have done near Cambridge, where, he told me, he had seen the coprolites accumulated to a depth of 2 feet in such places.

At the time I was inclined to think the undulations were here produced by small local rolls in the beds themselves, but have since thought it possible that a slight erosion of the Gault below the nodules may have caused them; and I am rather disposed to look upon every band of *black* phosphatic nodules as representing the washings of some bed of clay or other material in which they were originally formed. This, however, raises the question of the actual formation of phosphatic nodules, into which I do not now desire to enter. My object is to trace the Cambridge coprolites to the "gisement" which they occupied before they were transferred to their present position; and I think enough has already been said to make it probable that this layer in the Gault was the home of a great many of them.

The same bed is worked again at Cheddington, three miles to the N.E., and near the London and North-western Railway. Here it is not quite so sandy as at Puttenham, the green grains occurring more in patches among the nodules. Still the quantity is sufficient to form a greensand, were the bed subjected to the action of running water or abrading currents.

Now this very operation is actually performed by the process of washing the coprolites; and one result of this is to leave a small heap of pure greensand near the washing-mill, of exactly the same appearance as the heaps in a similar position throughout Cambridgeshire.

Thus these sand-heaps clearly prove that, if the bed were to be eroded in a more natural manner, the result would be a clayey greensand containing numerous waterworn coprolite nodules, such as we find in the so-called Cambridge Greensand.

I lay much stress on this fact, because the occurrence of glauconite grains in the light-coloured indurated matrix which often fills the interior of the Cambridge nodules has been a difficulty to some geologists, preventing their acceptance of the Gault origin of the coprolites.

Thus Mr. Fisher speaks in the following terms*:—"The indurated matrix which fills the axes of the cylindrical nodules was in all probability introduced while the fossils were in their original *gisement.* Hence we gain a clue to the derivation of the fossils of the thin crowded layer of the so-called Upper Greensand of Cambridge. They seem to have been washed out of a calcareous marl similar in character to the marl which lies above it. In short, the nodule-bed is a condensation of the 'Chalk-marl with glauconite grains.'" He proceeds to say that he believes this to be a much more probable account of the derivation of these nodules than that which attributes them to the denudation of the Gault, since these are for the most part smaller, "dwarfed, as if the muddy waters of the Gault sea did not suit them; they are also very sparsely scattered in the clay."

This is quite true of the Cambridge Gault; but if it has suffered denudation, the beds which really furnished the coprolites would no

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* "On Phosphatic Nodules," Quart. Journ. Geol. Soc. vol. xxix. p. 61.

longer be there. These statements, moreover, cannot be applied to the Upper Gault of Bucks, where Mr. Fisher will find the coprolites to be of larger size, dark-coloured, and accumulated in a bed fully equalling the thickness and sandiness of the Cambridge stratum. The nodules from the marly and clayey greensands above-mentioned would necessarily be filled with a similar matrix. The Gault, moreover, above these beds is so marly and light-coloured that it might easily be mistaken for Chalk-marl on a first inspection.

Resuming the track of the Gault nodule-bed, another pit is found between Cheddington and Northall, showing a similar section, namely :—

4\. Gravel and top earth.
3\. Light slate-coloured gault.
2\. Coprolite-bed with green grains.
1\. Dark blue gault.

I obtained here the following fossils :—

Ichthyosaurus (vertebræ).
Otodus appendiculatus, *Ag.*
Ammonites splendens, *Sow.*
—— cratus, *Seeley.*
Plicatula pectinoides, *Sow.*
Spondylus gibbosus, *D'Orb.*
Pleurotomaria, sp.

These and the fossils in the preceding lists are all species common in the Upper Gault of Folkestone and in the Cambridge Greensand.

Mr. Wilkerson, of Leighton Buzzard, who manages the workings at Cheddington and Northall, informs me that the thickness of the Gault below the coprolite-bed is here about 150 feet, while to the south, at Eddlesborough, it has a total thickness of 205 feet; this, therefore, leaves about 50 feet of Gault above the seam of coprolites, which I propose to consider the line of separation between the Upper and Lower Gault in this area.

The line of workings which we have been following is continued by another pit at Northall Common, and a fifth near Billington; but these I had not time to visit. Beyond this I am not aware of any workings in the bed; but Mr. Wilkerson told me that in the second cutting in the railway, north of Harlington, the same band of coprolites was met with, and light-coloured clay above them.

Mr. Pearse, of Harlington, also told me that coprolites occurred about 20 feet down in the clay-pit on the right-hand side of the road to Toddington.

Again, at Grange Mill, near Sharpenhoe, two layers of coprolites were visible in a road-side cutting, surmounted by the usual light marly clay of the Upper Gault.

At the pits between Barton and Sharpenhoe the foreman told me that he had bored for this lower seam on the other side of the road, just outside the boundary of the Chalk-marl, and found it at a depth of 18 feet. We may place its horizon here, therefore, at about 20 feet below the Cambridge bed, or 30 feet nearer the surface of the Gault than it was ten miles further back to the S.W. This, then, clearly shows either that the surface of the Gault is an inclined plane, or that the nodule-bed below is inclined and rises upward towards the surface. Beyond this point I could find no sections or exposures until I reached Shillington, four miles to the N.E.

Here I made diligent inquiries about the Gault nodule-bed; but the foremen and well-sinkers knew nothing of any such seam, though all agreed in asserting the existence of another bed of coprolites, about 180 feet down, near the bottom of the Gault, which has here the usual thickness of 200 feet.

This bottom bed I found was worked near Campton, about two miles to the northward, and I subsequently visited the pit; but the seam of coprolites had of course no connexion with that I was searching for.

At Arlesey, a few miles to the east (see Map, p. 259), there is a large brickyard where excavations have been made to a depth of 50 or 60 feet in the Gault; and if any nodule-band existed near the surface, it would be discoverable in the steep sides of this pit. These I carefully examined, but without finding any band or seam of coprolites; nor did the men at work know of any such bed.

I think, therefore, we are driven to one of two conclusions regarding the Buckingham nodule-bed—either that it has thinned out before reaching Shillington, or that it has cropped out into the Cambridge bed somewhere between that place and Barton. In order to decide this point completely, it would probably be necessary to institute a series of borings over the district; but I am strongly inclined to believe that the latter supposition represents the true state of the case.

At the last place where I saw the bed (not five miles from Shillington) it showed no signs of thinning out; there is, moreover, the remarkable coincidence that both the Cambridge and Buckingham beds are last seen in the neighbourhood of Barton, and the fact that they are there only 20 feet apart from one another. Under the circumstances, therefore, I conclude that the stratum which is worked for "coprolites" in Bucks has furnished some, at least, of the fossils and nodules now composing what has been called the Cambridge Upper Greensand.

§ 5. *The Gault and Greensand of the Weald.*—I have now described the relations of the strata in the districts which border upon the Cambridge area; but before drawing my conclusions from the evidence thus obtained, it will be desirable to take a short survey of the deposits of a similar age in the Weald of Kent, which are capable of throwing much light upon the question in hand.

The following details are derived partly from my own notes made at the commencement of this year, and partly from those of Mr. Price and Mr. Topley, to whom my thanks are due for their ready kindness in imparting such information as they possessed.

Commencing, then, with the well-known section at Folkestone, the thickness of the Gault here is given as 100 feet by Mr. Price, who divides it into a lower and an upper division*. The main part of the latter is formed by the bed numbered XI. in Mr. Price's paper, which is 56 feet thick, and includes a band of fossiliferous and

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* "On the Gault of Folkestone," Quart. Journ. Geol. Soc. vol. xxx. p. 342.

noduliferous greensand, not dissimilar to the matrix of the Cambridge phosphate-bed. It is thus described by Mr. Price:—

		ft.	in.
XI.	*c.* Pale-coloured marly clay	17	6
	b. Middle greensand, with nodules	3	3
	a. Pale grey clay resting on a band of nodules with *Pecten Raulinianus*	35	6
	Total	56	3

The nodules in this greensand bed are of two kinds, as at Cambridge—some black, waterworn, and irregular, others light brownish grey in colour, and evidently formed in the bed itself, since they include glauconite grains and are often attached to the black nodules; sometimes two or more of the latter are cemented together by this light phosphate, exactly in the same way as many of the Cambridge coprolites are bound together.

The fossils of bed XI. are nearly all found at Cambridge; and among the commonest are *Solarium ornatum*, *Avicula gryphæoides*, and *Plicatula pectinoides*.

Above the Gault comes a dark green sandy bed, about 10 feet thick, and almost entirely made up of glauconite grains; this represents the Upper Greensands. It appears to rest with a somewhat uneven surface upon the clay below; and its contents are mainly sponges of the genus *Brachiolites*, few other fossils having been found in it.

The next succeeding bed is of about the same thickness, but much lighter in colour, being a whitish marl with scattered green grains; this passes into the yellowish grey rock of the Chalk-marl.

Such is the section in Eastwear Bay; but when traced inland differences are soon apparent: the dark Upper Greensand thins out entirely in a few miles, allowing, it is said, a thin band of Chloritic Marl to come down on the Gault.

There are no good sections, however, to be seen until we arrive at Aylesford, near Maidstone, where there is a large brick-pit, in the cliffs of which the following remarkable section is exposed:—

	ft.
3. Chalk-marl passing down into light green sandy marl	10
2. Basement-bed of greenish marly sand containing rolled black coprolites	1
1. Bluish grey Gault, with a thin band of brownish clay at the top	30 shown

We have here, then, precisely the same conditions as at Cambridge—namely an absence of Upper Greensand, and a coprolite bed at the base of the Chalk-marl—though the nodules here are not so abundant, and the bed would not pay to work.

The explanation I consider to be the same in both cases; and at Aylesford, I believe, it is the removal of the beds representing the top 30 or 40 feet of bed XI. at Folkestone which has caused the above-mentioned appearances.

About 20 feet down in the clay I found many specimens of *Inoceramus sulcatus* and *Ammonites varicosus*, which at Folkestone characterize the base of the Upper Gault, and are not known in bed XI. The fossils obtained between 30 and 40 feet down were distinctly those of the Lower Gault.

It is remarkable, however, that the Gault, taken as whole, is considerably thicker in this neighbourhood, instead of being thinner, as I should have expected; for a few miles further west, at Burham, two borings gave respectively the depths of 160 and 200 feet; but perhaps the greater thickness of the Gault here was in reality the very cause of the denudation; for it might have formed a great roll or bank in the Chalk sea, the top of which would naturally be exposed to erosion.

However this may be, there is no doubt about the relations of the strata; and these seem to continue with an absence of Upper Greensand as far westward as Westerham; here, however, hard beds of "firestone" and "malm rock" come in below the Chalk-marl, and rapidly acquire thickness and importance. Under these the uppermost sandy beds of the Gault seem again to be present; and on this point I may quote the words of Mr. Godwin-Austen in a paper describing the phosphate-beds near Guildford[*]. He says, "the phosphate nodules are abundant in the Upper Greensand, but are generally small in the top beds; below comes the firestone or malm rock 20 to 25 feet thick, and beneath this again other beds of bright green earth, of which one portion is argillaceous; this lower green band is the Gault. The concretions of phosphate of lime are not scattered throughout it, but occur in two seams—one in the argillaceous portion, the other lower and only a little within the limits of this division of the series. These two beds of phosphate nodules, as well as a seam of pyrites staining the Gault of a brown colour, are remarkably persistent."

Along the foot of the South Downs very little appears to be known of the Gault and Greensand; but at Eastbourne there is again a cliff-section, of which my friend Mr. Maddock has favoured me with the following particulars:—

	ft.
Chalk-marl, with basement-bed consisting almost entirely of *Brachiolites labyrinthicus*	—
Chloritic marl, with numerous phosphate nodules and fossils about	8
Upper Greensand, soft green sands with a hard band of rock in the middle	26
Upper Gault, grey sands with clay below, containing the usual fossils of the division	8 shown.

In reviewing the above descriptions and sections, let me remark that in three of the localities mentioned the sands of the Upper Gault are present, with fossils and phosphate nodules; while in the fourth they are absent, and there conditions prevail similar to those so well known at Cambridge. This fact cannot but have much weight in considering the reason of such conditions.

§ 6. *Conclusions from Stratigraphical Evidence.*—A fair consider-

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[*] See Quart. Journ. Geol. Soc. vol. iv. p. 257.

ation of the facts and statements given in the foregoing pages will, I think, inevitably lead to the following conclusions:—

(1) That the Cambridge Greensand or nodule-bed has no connexion whatever with the Upper Greensand or with the Warminster beds, its actual position being above their horizon and at the base of the true Chalk-marl.

(2) That the same bed rests everywhere unconformably on the clay below, and that the coprolites, fossils, and green grains which it contains have been mainly derived from the denudation of the Upper Gault, a formation which originally extended much further in a north-east direction than it does now, but which is still well developed in Buckinghamshire.

(3) That in consequence of this erosion a great gap now exists between the Lower Gault and the Chalk-marl in Cambridgeshire—the whole of the Upper Gault, Upper Greensand, and Chloritic Marl being absent, the first-named from denudation, the last two from original non-deposition.

There are still a few observations I wish to offer in support or explanation of the conclusions arrived at above.

(1) In following the Chalk-marl westward beyond the termination of the Cambridge bed, we found it eventually underlain by the true Upper Greensand in the shape of soft sands and calcareous sandstone, the former composing, at any rate in Berkshire, the chief and most fossiliferous part of the formation. It thus continues, I believe, through Wiltshire into Devon; in this county it has been described by more than one observer, the last being Mr. C. J. A. Meyer, who, in a paper read before the Society last session, gave a careful description of the rocks of Beer Head and the adjacent cliff-sections*. Among the beds there exhibited he identifies the Chloritic Marl in its usual position, and he maintains from a comparison of faunas that the Warminster Greensand is also Chloritic Marl. If this should prove to be correct, I think the Wantage sands will have to occupy the same horizon, and the name Chloritic Marl would simply indicate the topmost beds of the series hitherto called Upper Greensand. According to Mr. Meyer the top of this Chloritic Marl presents an uneven surface at its junction with the lowest bed of the Chalk-marl, which, moreover, contains numerous phosphatic nodules. Regarding the contents of this nodule-bed he observes (p. 378) that "many of the fossils seem to have been deposited in the condition of casts; and some at least of these may have been derived from a partial wearing away of the Chloritic Marl." Finally he remarks "that this line of erosion is a fact of much importance in its bearing on Cretaceous geology."

In Devon, therefore, as in Cambridge, the Chalk-marl contains a band of phosphate nodules at its base resting unconformably on the beds below; whether this line of erosion can be traced in the intermediate country remains to be seen. I quite agree, however, with Mr. Meyer in his estimation of the importance of these facts; and seeing how much more persistent and continuous the Chalk-marl is

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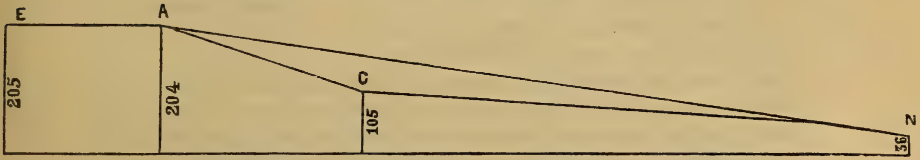
* See Quart. Journ. Geol. Soc. vol. xxx. p. 369.

than the beds below, apparently marking the cessation of current-action and the commencement of deep-sea conditions, I am inclined to believe that a stronger line of division will have to be drawn at its base than has hitherto been thought necessary.

(2) With regard to the denudation of the Gault, it is very difficult to know how much of the diminution in thickness through Cambridgeshire is due to denudation, and how much to thinning out. There can be no doubt that the formation does become thinner both to the north and the west. At Harwich it is only 40 feet thick, at Norwich 36; and in West Norfolk, near Lynn, it disappears altogether*. But by taking a line on Norwich and constructing the following diagram (fig. 4), we may gain some idea of the amount of rock removed by denudation in excess of the normal thinning-out.

Fig. 4.—*Diagram representing the Erosion of the Gault over Cambridgeshire.*

(Horizontal scale, 20 miles = 1 inch; vertical, 300 feet = 1 inch.)



E. Eddlesborough. A. Arlesey. C. Cambridge. N. Norwich.

The line AN representing the original surface of the Gault, and ACN the present denuded surface, the area enclosed between them may be taken as a measure of the amount of clay thus removed, amounting over Cambridge to 60 feet. How far the coprolite-bed extends under the chalk towards Norwich cannot of course be known until more deep wells have been sunk.

(3) I see no reason to suppose that the Upper Greensand ever extended further north-eastward than Buckinghamshire; and the following diagrammatic section (fig. 5) represents my view of the relations of

Fig. 5.—*Diagrammatic Section through Bedfordshire.*

a. Lower Gault.
b. Upper Gault.
c. Upper Greensand.
d. Chalk-marl.
e. Coprolite-bed at base of Chalk-marl.

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* I am inclined to think that the beds described as Upper Greensand at Harwich and Norwich are more probably referable to the sandy upper portion of the Gault; if so, the numbers above given would stand corrected thus—Harwich 61, Norwich 42.

the strata in Bucks and Bedfordshire. This I interpret to mean, that while sandy material was being deposited on the Gault in the south-west of England, that formation was being gradually denuded over the space occupied by the counties of Cambridge, Herts, and East Bedford; and the result was the formation of the well-known phosphate-bed when this period of erosion had come to an end. Between these two areas, that of deposition on the one hand and denudation on the other, there seems to have existed a tract where neither the one nor the other obtained; this extended from Harlington, in Bedfordshire, to the borders of Buckinghamshire; and from the time of the Upper Gault there seems to have been no deposition of any material over this area until it sank beneath the waters of the Chalk-marl sea.

The same results may be represented, and perhaps more clearly, in three comparative columns:—

	Cambridge.	*Bedford.*	*Buckingham.*
5.	Chalk-marl.	Chalk-marl.	Chalk-marl.
4.	——	——	Chloritic Marl ?
3.	——	——	Upper Greensand.
2.	(absent by erosion).	Upper Gault (in part).	Upper Gault.
1.	Lower Gault.	Lower Gault.	Lower Gault.

The above inferences and remarks follow from a consideration of the stratigraphical evidence alone; and with the object I have in view, viz. that of determining the true position of a given stratum, such evidence is usually of more value than that derived from a comparison of the fossils with those of other more or less distant localities. In the present instance, however, the very fact which is prominently brought out by the above inquiry, viz. that many of the Cambridge fossils are likely to have been derived from underlying beds, necessitates a thorough and exhaustive study of the fauna; and in the following pages I have endeavoured to do justice to this part of the subject.

I desire to record my obligations to Mr. Bonney, and to Messrs. Whitaker and Penning, of the Geological Survey, for suggestions and information relative to the preceding part of my paper; and I heartily thank them for the interest they have taken in its preparation.

Part II.—Palæontological Relations.

§ 1. *Natural Division of the Cambridge Fauna.*—The fossil contents of the Cambridge Greensand are readily divisible into two groups or faunas, distinguished by the different states of preservation which their respective components exhibit: the one of these is derivative; the other is *in situ*, and belongs to the sandy marl of the formation.

The fossils composing the one fauna are mineralized by a dark phosphate of lime, either dark brown or nearly black in colour. The bones are nearly always much rolled and worn. The molluscan remains occur usually in the form of more or less waterworn casts, the shell being either entirely removed or else, as is sometimes the case, replaced by calcic phosphate; among the Ostreidæ, however, the original calcareous shell is often well preserved. The Crustacea frequently retain their tests, apparently in a phosphatized condition; but the limbs are seldom found attached. The Echinoderms and Corals nearly always occur as waterworn casts, the former only occasionally retaining remnants of their calcareous shell.

Finally, it may be noticed that these dark-coloured fossils and nodules are always met with at the very bottom of the bed, and are much covered with small *Plicatulæ*, *Ostreæ*, and *Spondyli*.

The second group of fossils (see list, p. 311) comprises specimens which are obviously of the same age as the bed itself, and are easily separated from the former by the difference of their mineral condition.

The bones are more perfect, lighter in colour, and their interstices are usually filled with the sandy marl of the formation; this causes them to be more friable, and when they have been washed in the mills they often appear as rolled and broken as their darker companions; but this is not the case when they are taken fresh from the deposit itself.

The Mollusca of this fauna are chiefly Lamellibranchs and Brachiopoda, and in all cases the calcareous shells are preserved; their interiors are either filled with indurated sandy marl, or with a substance which is apparently half calcareous half phosphatic in its composition; and it is these lighter phosphates which range upwards into the Chalk-marl.

Amongst the lesser débris several small Brachiopods, Corals, Echinoderm-spines, and Foraminifera may always be discovered.

Finally, it may be remarked that many of the species are essentially characteristic of the lower beds of the Chalk.

For further information regarding the condition of the various organic remains I may refer to Mr. Bonney's paper previously cited, and to papers by Mr. Sollas in the Quart. Journ. Geol. Soc. vol. xxviii. p. 397, and Geol. Mag. vol. x. p. 268. I may remark, however, that the shells of the Ostreidæ seem to possess some peculiarity of structure or composition which enables them to resist wear and tear, as well as dissolving agents, much better than others. The shells of those in the nodule-bed are almost always preserved, and though many of them are of the same age as the deposit, others which are certainly derived still retain their shell in a more or less good state of preservation; consequently in some cases it is difficult to say to which fauna a given individual most probably belongs. The internal cast is a good criterion, and when that consists of clean dark phosphate there is no doubt of its derived origin. The cases of light phosphate with black phosphate pebbles are more ambiguous.

Both Mr. Bonney and Mr. Walker have noticed the presence of two distinct faunas in the formation, the former at p. 13 of his paper on the subject, and the latter in a note to one of Mr. Davidson's papers on Continental Geology. Mr. Walker here gives his reasons for believing that the Cambridge bed has resulted from the denudation of the Gault; and after remarking upon the waterworn character of the fossils, the rareness of associated bones, and the frequent presence of small oysters, &c. on the fractured surfaces of bones and nodules, he says, "it is possible that *Terebratulina gracilis* and some others may be of the age of the deposit, and may be found at the base of the Chalk"[*]. This opinion he will find abundantly confirmed by the lists appended to this paper, and the facts herein recorded.

§ 2. *Further Analysis of the Fauna.*—Although the fossils are only divisible into two groups as far as regards their present mineral condition, it would appear that there are representatives of a third fauna among them; for though the fossils from the Lower and Upper Gault are in the same state of preservation, the faunas of these two divisions are really very distinct, that of the former answering to the *Albien*, and that of the latter to the Gault supérieur, or *Vraconnien* of Swiss geologists[†]. Now although most of the Cambridge fossils, and especially the commoner species, belong clearly to the Upper Gault, yet many characteristic of the Lower also occur, in consequence of the extensive denudation which, I believe, the whole Gault formation has undergone over this area.

We have therefore a strange mixture of forms in this narrow little band of rock; and the appended list of derived fossils would not, if taken as it is, point definitely to the horizon whence most had been derived, or to the fauna which they may be said to represent. The strong Upper-Gault character of the assemblage only comes out when the more abundant forms are taken as a basis of comparison. Our first care therefore must be to separate out those species which are of very rare occurrence, and likewise those which, being only known in this bed, afford no means of comparison. The first of the following lists contains those which have been cited as new species by Mr. Seeley and others, and have not since been recognized in any other formation; the second includes the rarer fossils of the bed. Mr. Seeley's species are described in the 'Ann. & Mag. Nat. Hist.' for 1861 and 1865.

List of Fossils peculiar to the Cambridge Greensand.

Ammonites glossonotus, *Seeley.*
—— acanthonotus, *Seeley.*
—— sexangulatus, *Seeley.*
—— —— *var.* rhamnonotus, *Seeley.*
—— Woodwardi, *Seeley.*
—— leptus (*var* of splendens).

Pterodonta marginata, *Seeley.*
—— longispira, *Seeley.*
Fusus tricostatus, *Seeley.*
—— quinquecostatus, *Seeley.*
Pyrula conoidea, *Seeley.*
Funis elongatus, *Seeley.*
—— brevis, *Seeley.*
Pterocera globulata, *Seeley.*
Scalaria angularis, *Seeley.*
—— tenuistriata, *Seeley.*
Neritopsis scalaris, *Seeley.*
Mesochilostoma striata, *Seeley.*
Pleurotomaria Jukesii, *Seeley.*
—— semiconcava, *Seeley.*
Solarium planum, *Seeley.*
—— Carteri, *Seeley.*
—— Sedgwickii, *Seeley.*
Littorina crebricostata, *Seeley.*
Trochus cancellatus, *Seeley.*
Turboidea nodosa, *Seeley.*
—— expansa, *Seeley.*

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[*] 'Geol. Magazine,' vol. vi. p. 259, note.

[†] That the Gault supérieur is rightly so named, and is not equivalent to our English Upper Greensand, I hope to show in a further paper, which is already advanced towards completion.

Tornatella pyrostoma, *Seeley.*
Stomatodon politus, *Seeley.*
Acmæa tenuistriata, *Seeley.*
Galericulus altus, *Seeley.*

Ostrea cunabula, *Seeley.*
—— lagena, *Seeley.*
Pecten Barretti, *Seeley.*
Hinnites pectinatus, *Seeley.*
Perna oblonga, *Seeley.*
—— semielliptica, *Seeley.*
Nucula rhomboidea, *Seeley.*
—— subelliptica, *Seeley.*

Eucorystes Carteri, *M'Coy.*
Xanthosia granulosa, *M'Coy.*
Etyus similis, *Bell.*
Glyphæa Carteri, *Bell.*
Phlyctisoma tuberculatum, *Bell.*
—— granulatum, *Bell.*

Scillaridea cretacea, *Seeley*, MS.
Squilla McCoyi, *Seeley*, MS.

Pseudodiadema scriptum, *Seeley.*
—— inversum, *Seeley.*
—— intertuberculatum, *Seeley.*
—— fungoideum, *Seeley.*
—— Barretti, *Woodw.*
—— Carteri, *Woodw.*

Bonneyia cylindrica, *Sollas.*
—— Jessoni, *Sollas.*
—— scrobiculata, *Sollas.*
—— verrongiformis, *Sollas.*
Polyacantha Etheridgii, *Sollas.*
Acanthophora Hartogii, *Sollas.*
Retia costata, *Sollas.*
Hylospongia patera, *Sollas.*
—— calyx, *Sollas.*
Sarcinula favosa, *Mich.*

List of the rarer Phosphatic Fossils.

Name.	Lower Gault.	Upper Gault.	Gault supérieur.	Upper Greensand, &c.
Belemnites minimus, *List.*	*	*	*	
Ammonites Salteri, *Shpe.*	......	......	....	*
—— latidorsatus, *Mich.*	*	......	*	
—— Timotheanus, *Mayor*	......	......	*	
—— Renauxianus, *D'Orb.*	......	......	*	*
—— dispar?, *D'Orb.*	......	*	*	
Turrilites Bergeri, *Brong.*	......	*	*	*
Hamites virgulatus, *Sow.*	*	......	*	
Helicoceras Robertianus, *D'Orb.*	......	......	*	
—— 4-tuberculatus.				
Ancyloceras tuberculatus, *Sow.*	......	*		
Pterocera Fittoni, *Forbes*	*?			
—— retusa, *Sow.*	*	......	*	
Rostellaria Parkinsoni, *Sow.*	*	......	*	
—— carinata, *Mant.*	*	*		
—— elongata, *Sow.*	*			
Buccinum gaultinum, *D'Orb.*	*			
Fusus Smithii, *Sow.*	*			
Natica gaultina, *D'Orb.*	*	*	*	
—— clementina, *D'Orb.*	*			
Avellana Hugardiana, *D'Orb.*	......	......	*	
—— ventricosa, *Seeley*	......	......	*?	
Cerithium Mosense?, *Buv.*	*	......	*	
Crepidula Cooksoniæ, *Seeley*	......	......	*	
—— gaultina, *Buv.*	......	......	*	
Pecten orbicularis, *Sow.*	*	*	*	*
Lima globosa, *Sow.*	......	*	....	*
—— elongata, *Sow.*	*	*	*	
Neithea quadricostata, *Sow.*	*	*	*	*
—— quinquecostata, *Sow.*	*	*	*	*
Carried forward	17	11	20	7

List (*continued*).

Name.	Lower Gault.	Upper Gault.	Gault supérieur.	Upper Green-sand &c.
Brought forward	17	11	20	7
Inoceramus sulcatus, *Park.*	......	*	*	
—— concentricus, *Park.*	*	*	*	*
Perna subspathulata, *Reuss*	*			
Gervillia solenoides, *Defr.*	*			
Arca carinata, *Sow.*	*	*	*	*
—— Hugardiana, *D'Orb.*	*	*	*	
Nucula albensis, *D'Orb.*	*			
—— Vibrayeana, *D'Orb.*	*	......	*	
Leda solea, *D'Orb.*	*			
Cucullæa fibrosa, *Sow.*	*	......	*	
Isoarca Agassizii, *Pictet*	......	......	*	
Lucina tenera, *Sow.*	*			
Fimbria gaultina, *Pictet*	......	......	*	
Cardita tenuicosta, *Sow.*	*	*	*	
Tellina phaseolina, *D'Orb.*	*	......	*	
Pholadomya decussata, *Sow.*, var.	*			
Rhynchonella compressa, *Lam.*	......	......	....	*
—— latissima, *Sow.*	......	......	....	*
Diaulax Carteriana, *Bell*	......	*		
Cyphonotus incertus, *Bell*	......	......	....	*
Hemioon Cunningtoni, *Bell*	......	......	....	*
Necrocarcinus Woodwardi, *Bell*	*	......	....	*
—— tricarinatus, *Bell*	*	......	....	*
Homolopsis Edwardsii, *Bell*	*			
Hoploparia scabra, *Bell*	*			
Cidaris gaultina, *Forbes*	......	*		
Hemiaster asterias?, *Forbes*	*	*		
Ventriculites mammillaris, *Smith.*				
Cephalites compressus, *T. Smith.*				
—— guttatus, *T. Smith*	......	* ?		
—— capitatus, *T. Smith.*				
Brachiolites tubulatus, *T. Smith.*				
Total 62	35	20	30	15

An inspection of the latter of these two lists shows that by far the larger number of the rare fossils belong either to the fauna of the Lower Gault or to the *Vraconnien*. That the latter fauna should be so largely represented in the above list is to be accounted for by the fact that it also contains a number of lingerers from the lower beds ('Faune de Cheville,' p. 198*), while 12 out of the 30 are species peculiar to the continental Gault supérieur; and being unknown elsewhere in England, it is not surprising that they should be rare at Cambridge.

The number of Lower Gault forms (35) is more significant, and seems to show that the denudation near Cambridge had reached the beds of that formation; while their rarity indicates either how small a portion of those strata had suffered erosion, or, what I think more probable, how unfossiliferous it has been.

* Renevier, "Faune de Cheville," Soc. Vaudoise des Sc. Nat. tome ix. p. 389.

Were it not for the number of species and paucity of individuals, their presence might be accounted for by supposing their range to have here extended into higher beds. Three other species of the Folkestone Lower Gault appear to have so extended their range, viz. *Ammonites auritus*, *Nucula bivirgata*, and *Trochocyathus angulatus*; but they are comparatively abundant fossils at Cambridge, while it is the rarity of the species under consideration which argues their actual derivation from Lower Gault, a conclusion which entirely agrees with the evidence obtained from the strata themselves; for, as before mentioned, the Lower Gault is worked for coprolites near Campton, in Bedfordshire. Here the well was sunk 28 feet, which, allowing 8 feet for Lower Greensand, agreed very well with the information obtained at Shillington about a coprolite seam 180 feet down. By the kindness of the manager, Mr. T. W. Balls, I obtained the following fossils from the washed heap:—

Belemnites ultimus, *D'Orb.*
—— attenuatus, *Sow.*
Ammonites lautus, *Sow.*
—— auritus?, *Sow.*
—— interruptus, *Brong.*
—— Beudanti, *Brong.*
Hamites rotundus, *Sow.*
Natica gaultina, *D'Orb.*
Rostellaria elongata, *Sow.*
Plicatula pectinoides, *Sow.*
Inoceramus concentricus, *Park.*
—— —— (large variety).
Nucula pectinata, *Sow.*
Terebratula biplicata, *Sow.*

The last of these (*Terebratula biplicata*) has never before been found at so low an horizon; I obtained it myself, however, on the spot. Many of the nodules were of large size, and the whole assemblage is similar to that in beds I. and II. in the Folkestone section.

Again, throughout the Cambridge Gault bands of coprolites are not uncommon. Mr. Bonney has kindly furnished me with a note on their occurrence in the great Gault pit at Barnwell: in the upper part he found irregular layers and scattered nodules of a pale buff colour externally, but dark inside (among them he noted specimens of *Rhabdospongia*, *Bonneyia*, and *Hylospongia*); about 20 feet down he found a thicker seam of larger nodules, and below this more coprolites scattered sparsely; other fossils are rare in the Cambridge Gault, but I have myself obtained *Ichthyosaurus* (vertebræ), *Plicatula pectinoides* (fairly common), *Trochocyathus angulatus*, *Hamites*, sp., *Terebratula biplicata*, *Nucula pectinata*.

Higher beds might have been more productive, and have furnished some of the fossils now in the Cambridge Greensand, as suggested above.

The total number of species, excluding Vertebrata, which are at present reckoned in the Cambridge derived fauna is 210: deducting, therefore, from this number all the species contained in the two preceding lists as only impeding comparison with other faunas, we have 85 remaining, which are at least tolerably common in the vicinity of Cambridge, and 66 of which (or 78 per cent.) are found in the English Gault; of these, 60 (or 71 per cent.) occur in the Upper Gault of Folkestone and Bucks; again, 62 out of the 85 (or 73 per cent.) are found in the *Vraconnien* of Prof. Renevier. If we only except from the original 210 those which are unknown in any other formation, in number 63, there are 147 left, out of which 109 are common to the Gault (this gives 74 per cent.), and of these, 80 (or 54 per cent.) are characteristic of the upper stage; the percentage of *Vraconnien* forms is a little less than before, viz. 92, or more than 62 per cent. The above numbers show how much the fauna resembles that of the Upper Gault; but the close relation which exists between them is still more prominently brought out when the most common fossils are alone considered. It is these which always indicate the true affinities of a fauna, whereas a catalogue of the whole assemblage often prevents a proper estimation of its true character.

The present being just such a case, I have prepared the following list of common fossils, most of which may be picked up on any heap near Cambridge; of these, all except four may be found in the Upper Gault of England, and these are supplied by the Gault supérieur of the Continent.

List of common Cambridge Fossils.

Names.	Lower Gault.	Upper Gault.	Vraconnien.	Upper Green-sand.
Ichthyosaurus campylodon, *Carter*	*	*		
Otodus appendiculatus, *Ag.*	*	*	*	*
Edaphodon Sedgwickii, *Ag.*	*	*		
Belemnites ultimus, *D'Orb.* (var.)	......	*	*	*
Nautilus clementinus, *D'Orb.*	*	*	*	
—— albensis, *D'Orb.*	......	......	*	
Hamites intermedius, *Sow.*	*	......	*	
Ammonites rostratus, *Sow.*	......	*	*	*
—— Majorianus, *D'Orb.*	......	*	*	
—— splendens, *Sow.*	*	*	*	*
—— auritus, *Sow.*	*	*	*	*
—— Raulinianus, *D'Orb.*	......	*	*	
Solarium ornatum, *Sow.*	*	*	*	*
Pleurotomaria Gibbsii, *Sow.*	......	*	*	
—— Rhodani, *Brogn.*	......	*	*	*
—— Rouxi, *D'Orb.*	......	......	*	
Dentalium decussatum, *Sow.*	*	*		
Ostrea frons, *Park.*	......	*	*	*
—— vesicularis, *Sow.*	......	*	*	*
Exogyra Rauliniana, *D'Orb.*	......	*	*	
Avicula gryphæoides, *Sow.*	......	*	*	
Spondylus gibbosus, *D'Orb.*	......	*	*	
Plicatula pectinoides, *Sow.*	*	*	*	*
Perna Rauliniana, *D'Orb.*	*	*	*	
Terebratula biplicata, *Sow.*	......	*	*	*
Rhynchonella sulcata, *Park.*	......	......	*	
Palæocorystes Stokesii, *Mant.*	*	*		
Trochocyathus conulus, *Edw.*	*	*	*	
—— angulatus, *Duncan*	*	*		
Serpula articulata, *Sow.*	......	*		
Total 30	14	26	24	11

The following Table is drawn up to show the absolute number of species common to the two Cambridge faunas, and the others to which they bear any relation.

Table showing the Number of Species common to the Cambridge Faunas and those of other Formations.

Name of Fauna.	Number of Species.	Common Species.	Number of Species.	Name of Fauna.
Cambridge Coprolites (Gault fauna).	210	92	240	Gault supérieur, or Vraconnien.
" "	210	80	110	Upper Gault of Folkestone and Bucks.
" "	210	64	187	Lower Gault of Folkestone and Bucks.
" "	210	20	72	Upper Greensand (except that of Warminster).
" "	210	28	140	Warminster Greensand.
" "	210	21	60	Chalk-marl and Grey Chalk — Cambridge, &c.
Cambridge Greensand (indigenous fauna).	44	10	110	Upper Gault (England).
" "	44	8	240	Gault supérieur.
" "	44	12	72	Upper Greensand.
" "	44	14	140	Warminster beds.
" "	44	29	60	Chalk-marl and Grey Chalk.

Note.—These numbers do not include the species of Vertebrata.

This comparison of the faunas will also enable us to take another view of the two assemblages of fossils in the Cambridge Greensand, and to ascertain which of the other formations contains the greater percentage of Cambridge fossils.

Considering the derived fauna first, its closest relations are evidently with that of the English Upper Gault; 110 species are known in that formation, and 80 of them (or 73 per cent.) occur at Cambridge.

Only 39 per cent. of the *Vraconnien* fauna are found in the Cambridge bed; but the lowness of this percentage is greatly due to the mixed character of the *Vraconnien* fauna at Cheville, which contains many fossils belonging to higher horizons than that of the true Gault supérieur, as well as many foreign species unknown in England. The absolute number (92) is large.

With the Lower Gault its relationship is much more remote: 187 species have been found in this division by Mr. Price, and 64 of these (or little more than 34 per cent.) occur in the Cambridge Greensand; but it must not be forgotten that most of them are among the rarest fossils of that formation.

I have only been able to find 72 species belonging to undoubted Upper Greensand, viz. that of the Isle of Wight and the Malm rock and Firestone of the Wealden area: 20 of these (or 28 per cent.) are common to the Cambridge fauna; but most of them are bivalves with a wide range, very few of the Cephalopoda or Gasteropoda being among them, and none of the more characteristic fossils.

From the Warminster Greensand about 140 species have been recorded; but only 28 (or 20 per cent.) are also found among the Cambridge coprolites, and, with the exception of *Rhynchonella compressa,* none of these are characteristic Warminster fossils; there is therefore little affinity between the two faunas.

With regard to the fossils really belonging to the Cambridge Greensand, the numbers given in the above Table clearly demonstrate their relationship with the fauna of the Chalk-marl; eight species are described as peculiar, but nearly all the rest occur in the Chalk-marl or Grey Chalk. These strata, as exhibited near Cambridge, in the Isle of Wight, and at Folkestone, contain an invertebrate fauna numbering about 60 species; of these, 29 (or nearly 50 per cent.) are found in the Cambridge bed.

§ 3. *Conclusions from Palæontological Evidence.*—This being so, it follows that a distinct palæontological break, so to speak, exists between the two elements of the Cambridge fauna, a glance at the preceding Table showing how much more closely the one part is bound to the Upper and Lower Gault than it is to the Chalk-marl. And yet this distant resemblance to the Chalk-marl fauna is greater than its resemblance to that of Warminster or other Upper Greensand localities; if, therefore, we cannot ascribe the Cambridge fauna as a whole to the Chalk-marl, still less can we class it with the Upper Greensand. The explanation of the facts I conceive to be that, while conditions were inimical to the immigration of many new forms, a few species found it possible to prolong their existence through the intervening time; and I regard the course of events as having taken place somewhat in the following order:—Originally there existed over the Cambridge and Bedford area a considerable thickness of Upper Gault, becoming, as usual, more sandy towards the top, and containing a fauna of very similar facies to that of the Swiss Gault supérieur or *Grès Vert*; continuity of deposition, however, was then interrupted, and in place of any true Upper-Greensand beds being formed, those already existing were subjected to the action of strong marine currents, which sifted out their contents and mixed them up with foreign stones and boulders derived from more northern localities*.

This period of erosion appears to have lasted during the time that 50 or 60 feet of strata containing an Upper-Greensand fauna were being deposited in more southern areas; but the conditions which introduced such agencies gradually changing, the results of their work would be left on the sea-bottom and eventually would be incorporated with the next succeeding series of deposits, at the

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* See a note "On the Included Rock-fragments of the Cambridge Upper Greensand," by Sollas and Jukes-Browne, Quart. Journ. Geol. Soc. vol. xxix. p. 11.

same time imparting to them a peculiar character which would not be observable elsewhere.

This succeeding formation was the Chalk-marl; and hence in Cambridgeshire its lower strata exhibit so pebbly and sandy a constitution as to have caused them to be referred to the Upper Greensand. Now, however, both stratigraphical and palæontological evidence unite in showing this supposition to be erroneous; and I submit that even the lowest of these beds cannot any longer be called Upper Greensand. *Stratigraphically* it is Chalk-marl, and should be mapped and spoken of as such; but *palæontologically* considered, what is usually regarded as the characteristic part of its fauna undoubtedly belonged to that of the Upper Gault: and though it is quite an exceptional state of affairs for the majority of fossils contained in a bed to be of a different age from the stratum itself, still such is the case here; and I think, therefore, the species included in the "derived fauna" of the appended list should certainly be admitted as Upper Gault forms, and hereafter be quoted as belonging to that division.

These palæontological considerations bear upon another important question, viz. the age of the Hunstanton limestone. Mr. Seeley argues this to be Upper Greensand, chiefly on the ground of its containing so many of the Cambridge fossils; if, however, these belong to the fauna of the Upper Gault, this argument changes its direction, and points to the latter formation as one which the Hunstanton red rock may in part represent. This explanation would at any rate account for the mixture of species it contains, and also for the different opinions entertained regarding its age, some geologists maintaining it to be Gault, others as confidently calling it Upper Greensand.

I hope, however, to make this the subject of a future communication to the Society, in which I shall endeavour to trace the relations of the strata northward from Cambridge, as in this paper I have followed a line south-west of that town.

§ 4. *Remarks on the Determination and Synonymy of certain Species.*—The following observations are the result of a long and careful study of the Cambridge fossils; and I have been led to identify several hitherto unnamed species in consequence of having what I consider the right clue to the origin of the fossils in their derivation from the Gault.

It may therefore be objected that I have interpreted the forms so as to be in accordance with this preconceived theory. I am quite willing to admit it, and to acknowledge that a belief in the Gault origin of the fauna has led me also to doubt the accuracy of many previous identifications, and to look for their true representatives among the fossils of the Gault. At the same time I hold that there is nothing unscientific in such a mode of procedure, and that, in the present state of palæontology, it is very desirable to have some such guide amid the difficulties arising from the multiplication of species, and from the comparison of specimens in different states of preservation and mineralization.

Such guidance has, in the present instance at any rate, enabled me to add 16 more species to the lists of the Cambridge fauna, and to identify at least 12 others as belonging to different species from those to which they had been previously referred.

That in these additions and corrections I have not been led astray by theoretical considerations will, I think, be granted when they are confirmed by so high an authority as that of Mr. Etheridge. In the majority of instances he has been able to do this by reference to the Cambridge fossils in the Jermyn-Street collection, which he and Mr. Newton were kind enough to re-examine with me for the purpose; it is only a few rarer species, not represented in the Survey Museum, that stand on my authority alone.

The lists of Reptilia in the following catalogue are taken from Mr. Seeley's 'Index to the Remains of Reptilia, &c., in the Woodwardian Museum of Cambridge;' the names of new species herein mentioned are stated to be only provisional, and a note on p. xv of the above 'Index' is thus worded:—"These names are only intended for the convenience of students using the Museum, and are not necessarily to take rank as names of described species." In very few cases, so far as I am aware, has Mr. Seeley subsequently raised any of the specimens so named to the rank of species by a detailed description of the same; in default, however, of any other list of the Cambridge Reptilia, I have judged it best to admit all Mr. Seeley's names into my own catalogue, but have not included them in calculations of the number of species for comparison with other faunas. I have carefully examined the specimens in the Woodwardian Museum in order to separate the dark, rolled, derived bones from those preserved in Chalk-marl only; this is an easy task with the remains of the Dinosaurs, Ichthyosaurs, and Plesiosaurs, but becomes much more difficult with those of *Pterodactylus* on account of the different structure of its bones. I will not, therefore, be positive that *all* those entered under the Gault fauna have been derived therefrom, though bones of *Pterodactylus* have been found in the Folkestone Gault, and I am sure that many have been derived from that formation. The same is the case with the fish-remains of the Cambridge deposit.

The following remarks relate to the identification of some species, and to the synonymy of others hitherto regarded as distinct.

I have to thank Mr. Etheridge and Mr. Newton, of Jermyn Street, for assistance in this department.

PISCES.

LAMNA SUBULATA, Ag.

Lamna subulata, Pict. & Campiche, Ste.-Croix, i. p. 87, pl. xi. f. 1–8.

The teeth of this species have been recognized in the Woodwardian Museum as *Lamna*, sp. I entertain little doubt of their belonging to the above species, which MM. Pictet and Campiche refer to their subgenus *Odontaspis*. The teeth are long and subulate, with a slight sigmoidal curve from back to front, closely agreeing with the description and figures of the above authors*.

The fish-remains of the Cambridge bed have been much neglected, and many more species remain to be identified. *Otodus appendiculatus* has been made to include several forms of teeth, some of which not improbably belong to other species.

I am glad to say that Mr. T. W. Bridge, of Trinity College, and Demonstrator in the Museum of Comparative Anatomy, is investigating these fish-remains; and we may therefore hope soon to possess more knowledge about them, and to chronicle some fresh forms in our lists.

CEPHALOPODA.

NAUTILUS ALBENSIS, D'Orb.

Nautilus albensis, D'Orb. Prodrome, ii. p. 122; Pict. & Campiche, Ste.-Croix, i. p. 134, pl. xvii.

This shell, which is not uncommon in the Cambridge bed, has been named *N. radiatus* by Mr. Seeley. According to the observations of MM. Pictet and Campiche, pp. 117 *et seq.*, several species appear to have been confounded under this name, especially *N. neocomiensis*, D'Orb., and *N. Neckerianus*, Pictet. They limit the *N. radiatus* of Sowerby to a Chalk-marl species with a large umbilicus, and describe a fourth form from the Gault under the name of *N. albensis*, D'Orb., with which our Cambridge specimens closely agree; this is characterized by a very small umbilicus, and the position of the siphon near the internal edge of the chambers. I am not, however, fully persuaded of its specific distinctness from *N. Neckerianus*.

BELEMNITES ULTIMUS, D'Orb.

Belemnites ultimus, D'Orb. Pal. Fr. Sup. p. 24; Sharpe, Cret. Moll. pl. i. f. 17.

B. minimus (pars), Pict. & Camp. Ste.-Croix, i. p. 103, pl. xiii. f. 1.

This species, or at any rate those so named at Cambridge, is identical with the specimen (fig. 1) of Pictet and Campiche, which, together with forms like *B. minimus*, List., and *B. attenuatus*, Sow., they group under the name of *B. minimus*. In the text they remark that "the middle Gault of Sainte-Croix furnishes only young specimens (i. e. *minimus*), while the Upper Gault contains principally those of 35–50 millims. in length." It is just the same at Folkestone, though there is also a short and stout form of *B. ultimus* which is frequent in the Lower Gault. At Cambridge the most common form is the elongated *B. ultimus*; but I would suggest that they be all regarded as belonging to the same species, keeping the various names as those for varieties only which differ in size and growth according to circumstances and "station."

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* Another species has been named *L. raphiodon*; but this is an Upper-Chalk form, and the teeth appear to me to agree better with *Lamna gracilis*, Ag., as figured by Pict. & Camp. p. 88, pl. xi. figs. 9–18.

AMMONITES ROSTRATUS, Sow.

Ammonites rostratus, Sow. Min. Conch. pl. 173; Ooster, Céph. Alp. Suiss. p. 142, pl. xxvi. f. 1–3.
Ammonites inflatus, Sow. Min. Conch. pl. 178; Pict. & Campiche, Ste.-Croix, p. 178, pl. xxi. f. 5, pl. xxii. f. 3, 4.
Ammonites symmetricus, Sow. Geol. Trans. 2nd ser. iv. pl. xi. f. 21.

The form found in the Gault and Upper Greensand of England, which is large, somewhat compressed, and has fewer ribs, seems to be Sowerby's original *A. rostratus*; and the smaller, compressed, strongly ribbed form so common at Cambridge and also at Cheville is closely allied to this. They undoubtedly pass, however, into the *A. inflatus,* Sow., as figured by D'Orbigny and Pictet and Campiche, assuming an inflated shape, with numerous ribs broken up into tubercles; to this the inflated and closely ribbed form called by Mr. Seeley *A. pachys* is very nearly allied, and hardly constitutes a third variety*. *A. rostratus* being so abundant in the Upper Gault, and not being found below, may well give its name to the horizon, and consequently to the Cambridge nodule-bed, in which it equally abounds.

AMMONITES DISPAR, D'Orb.

Ammonites dispar, D'Orb. Pal. Fr. p. 143, pl. 45. f. 1, 2; Pict. & Camp. Ste.-Croix, p. 264, pl. xxxviii.

In his excellent paper on the *Ammonites* of the Cambridge Greensand (Ann. & Mag. Nat. Hist. ser. 3, vol. xvi.) Mr. Seeley describes some *Ammonites* under the name of *A. navicularis,* var. *nothus,* correctly noticing that "they are more flattened than is usual in examples of *A. navicularis* from the Chalk, and differ in never having any tubercles; the umbilicus is also commonly smaller."

In form they certainly approach *A. Mantelli,* and I have seen specimens of this species in which the ribs passed over the back without developing tubercles. The smaller Cambridge specimens might readily be taken for *A. Mantelli,* and, indeed, Mr. Etheridge was inclined to place the one I showed him with that species.

There are, however, two specimens now in the Woodwardian Museum of more adult age, in which the ribs become more distant, and finally more faint, apparently passing through some of the stages depicted in pl. xxxviii. of Pictet and Campiche as those of *A. dispar.* At p. 267 they remark:—"When this species is complete, and one can follow its modifications, it cannot be confounded with any other. When young it rather resembles *A. Mantelli* and *A. Milletianus*; it is always distinguished, however, by its more rapid 'enroulement,' its narrower umbilicus, and the disposition of its ribs, which, instead of alternating regularly large and small, are of unequal number, the larger being much less abundant and separated by several small ones." These characters equally apply to our spe-

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* It appears to me identical with that figured by MM. Pictet and Roux, Grès Verts, pl. 9. f. 6.

cimens; that named *Ammonites Wiestii* in the British Museum, and described by Mr. Seeley, belongs to the same species.

AMMONITES PLANULATUS, Sow.

Ammonites planulatus, Sow. Min. Conch. pl. 570. f. 5; Sharpe, Chalk Moll. pl. xii. f. 4.
Ammonites Mayorianus, D'Orb. Pal. Fr. i. p. 267, pl. lxxix.; Pictet, Grès Verts, p. 37, pl. ii. f. 5.
Ammonites octosulcatus, Sharpe, pl. xix. f. 3.
Ammonites Griffithsii, Sharpe, pl. xi. f. 3.

These appear to be only varieties of the same form (see the remarks of Mr. Seeley in Ann. & Mag. Nat. Hist. ser. iii. vol. xvi.). *A. planulatus* was originally described from a Chalk-marl specimen, and may be retained for the thicker forms of the group with a wider umbilicus, while the flatter forms so common at Cambridge agree better with those called *A. Mayorianus*.

It is interesting to find that these varieties succeed one another in point of time; MM. Pictet and Campiche (Ste.-Croix, p. 285) remark that the flatter types approach nearer to *A. Emerici*, an Aptien form, and that they are chiefly found in the Gault inférieur, which immediately succeeds the Aptien, "while *A. planulatus* becomes more frequent in the upper beds of the Gault and in the beginning of the Cenomanien period."

The relative abundance and state of preservation of the Cambridge specimens quite agree with the above remarks. The variety *Mayorianus* is always in black phosphate, and has come from beds some way down in the Gault; while the much rarer *planulatus* is preserved in brown phosphate, and has probably been derived from the upper sandy beds like those between the Gault and Chalk-marl described in the first part of this paper.

Many such examples of development are only waiting to be described by palæontologists, and to form strong evidence for Mr. Darwin's theory.

SCAPHITES MERIANI, Pict. & Camp. Pl. XIV. figs. 1–3.

Scaphites Meriani, Pict. & Camp. Ste.-Croix, ii. p. 16, pl. xliv.
?*Sc. Hugardianus*, D'Orb.; Pictet, Gr. Verts, pl. 12. f. 2.

The Cambridge *Scaphites* have always been regarded as *S. æqualis*; but Mr. Seeley correctly describes the form in Ann. & Mag. Nat. Hist. ser. 3, vol. xvi., and notices that there are three varieties: one he describes as the type which is ornamented with simple ribs, slightly elevated at the sides, and bifurcating before crossing the back: another he mentions as possessing a row of tubercles on each side; this form agrees with the *S. Meriani*, figured and described by MM. Pictet & Campiche. M. Renevier, however, marks *S. Hugardianus* as occurring at Cambridge (Faune de Cheville, p. 111). This species, as figured in the 'Grès Verts,' has only three tubercles, and the ribs are never obliquely curved, but run straight over the shell. I very much doubt whether this is more than a variety intermediate between *S. Meriani* and those first described with nearly simple ribs, which might receive the varietal name of *simplex*. They are easily distinguished from *S. æqualis*, Sow., by the convolute portion being so closely coiled as not to produce an umbilicus, as well as its much greater width across the back. In *S. æqualis*, moreover, the side ornamentation takes the form of greatly thickened ribs, instead of small tubercles.

ANISOCERAS, Pictet.

This genus was founded by M. Pictet in his 'Traité de Paléontologie,' tom. ii. p. 705, to include fossils resembling *Ancyloceras* in general form, but having the convolute portion twisted into an irregular spire, instead of lying in one plane. The genus does not seem to have been accepted in England; but I think it is certainly required, though the species it comprises cannot all be determined until the irregular Ammonitidæ of the Gault and Greensand are more thoroughly known. *Anisoceras*, in the character and ornamentation of its shell, is similar to *Hamites*, with which its species have chiefly been confounded.

ANISOCERAS ARMATUS, Sow.

Hamites armatus, Sow. Min. Conch. pl. 168.

Anisoceras armatus, Pictet & Camp. Ste.-Croix, p. 62, pl. xlviii. f. 1–6.

Anisoceras perarmatus, Pict. & Camp. Ste.-Croix, p. 65, pl. xlviii. f. 7, 8, and pl. xlix.

Large fragments of this shell are not uncommon on the Cambridge heaps, and appear chiefly to belong to the typical form, though some specimens agree with the figures of *A. perarmatus*. I cannot regard this latter form as any thing but a variety of *A. armatus*, from which it only differs in the width between the tubercles, the straightness of the ribs, and the smaller number of intermediate ribs; moreover, MM. Pictet and Campiche themselves figure a specimen which they regard as forming a transition (pl. xlix. f. 7).

ANISOCERAS SAUSSUREANUS, Pict.

Anisoceras Saussureanus, Pict. Ste.-Croix, ii. p. 67, pl. l. f. 1–3.

Hamites Saussureanus, Pict. Grès Verts, p. 118, pl. 13. f. 1–7.

Hamites Raulinianus, Oost. Céph. Alp. Suiss. v. p. 75 (non D'Orb.).

This species, so common at Cheville and Ste.-Croix, is not of such frequent occurrence at Cambridge, where, however, it is far from rare.

In this species the tubercles do not appear like buckles tying two ribs together as in *A. armatus*, but as simple rounded knobs on the larger ribs; these are also placed further apart and separated by numerous intermediate ribs, making a very different ornamentation. There are several other species of *Anisoceras* or *Hamites* among the Cambridge collections which await determination, or are possibly new species.

HAMITES VIRGULATUS, D'Orb.

Hamites virgulatus, D'Orb. Pal. Fr. i. p. 545, pl. 134. f. 1–4 (Brong. ?); Pict. & Roux, Grès Verts, pl. 14. f. 7–9; Ste.-Croix, p. 85, pl. liv. f. 6–12.

M. Pictet (Ste.-Croix, p. 85) was the first to recognize this species as existing at Cambridge. It is characterized by the possession of comparatively few, strong ribs crossing the shell nearly at right angles to its axis, and interrupted at the edges of its internal face, which they leave perfectly smooth.

It is a common fossil, occurring in all collections; I have also seen it from the Folkestone Gault.

HAMITES INTERMEDIUS, Sow.

Hamites intermedius, Sow. Min. Conch. pl. 62. f. 2, 3.
H. attenuatus, D'Orb. (? Sow.), Pal. Fr. pl. 131. f. 9–13.

I am inclined to think that *H. intermedius* and *H. attenuatus* are only different parts of the same shell. Sowerby (Min. Conch. p. 135) describes *Hamites* as hooked or bent into two parallel limbs; while D'Orbigny figures three limbs, saying at the same time (p. 535) that Sowerby's *H. tenuis, H. attenuatus,* and *H. compressus* are parts of one form. Instead of *compressus* I should rather be inclined to substitute *H. intermedius,* as having nearer relations with the other two; and this is Prof. Renevier's opinion (see Faune de Cheville, p. 104), except that he appears to have some doubt as to the identity of D'Orbigny's and Sowerby's *H. attenuatus. H. compressus* he considers to be a separate species; but the whole of this genus requires further investigation.

TURRILITES WIESTII, Sharpe.

Turrilites Wiestii, Sharpe, Ch. Moll. p. 68, pl. xxvii. f. 8, 9.

The specimens which I have identified with this species have been named *T. Bergeri* in the Woodwardian Museum; they are, however, clearly distinguished from that species by possessing only three ranges of tubercles, one sutural and two free; the transverse ribs also which bear the tubercles are not so numerous as in *T. Bergeri,* and are more distinct above the uppermost row. Altogether our Cambridge specimens agree closely with *T. Wiestii,* though they are not unlike the *T. costatus,* figs. 1 & 2 of Sharpe, which appear to me more allied to his *T. Wiestii* than to the true *T. costatus* of Lamarck. *T. Bergeri,* Brong., with its four ranges of tubercles, is also found at Cambridge, but appears to be much rarer than *T. Wiestii.*

HELICOCERAS ROBERTIANUS, D'Orb.

Helicoceras Robertianus, Pictet, Traité de Pal. ii. p. 713, pl. 56. f. 10.
Turrilites Robertianus, D'Orb. Pal. Fr. p. 585, pl. 142.

M. Pictet has transferred this species from the genus *Turrilites* to *Helicoceras,* in consequence of the whorls being slightly separated.

One fragment is preserved in the Woodwardian Museum, and another is in the cabinet of Mr. James Carter. A second species is represented by a well-preserved portion of a whorl, to which the name *H. quadrituberculatus* is attached, being, I suppose, a MS. name of Mr. Seeley's; it somewhat approaches *H. Thurmanni*, Pict. & Camp. p. 118, but has wider interspaces between the rows of tubercles.

BACULITES GAUDINI, Pict. & Camp.

Baculites Gaudini, Pict. & Camp. Ste.-Croix, ii. p. 112, pl. lv. f. 5–11.

MM. Pictet and Campiche (p. 113) say they possess a specimen from Cambridge belonging to the above species, and Mr. Etheridge agrees with me in considering that most of the Cambridge specimens belong to this form; there are, however, some fragments which he is inclined to refer to *B. baculoides*, Mant. Both are found in the Vraconnien of Cheville (Renevier); but *B. Gaudini* is the commoner, and is the only one found in the "Gault supérieur" of Sainte-Croix. At Folkestone it occurs, though rarely, in beds VI. and VII., or near the top of the Lower Gault. It differs from *B. baculoides* in having fewer and stronger ribs.

GASTEROPODA.

BUCCINUM GAULTINUM, D'Orb.

Buccinum gaultinum, D'Orb. Pal. Fr. p. 350, pl. 233. f. 1–2; Price, Q. J. G. S. vol. xxx. pl. 25. f. 1–2.

This species, which is well figured in the plate accompanying Mr. Price's paper, is found in the Lower Gault of Folkestone, beds VII. & VIII., but has not hitherto been recognized among the Cambridge fossils. In the Woodwardian collection, however, there is a Buccinoid cast, named *Rostellaria*, sp.!; and on comparing this with the casts of *B. gaultinum* from the Gault, I found so close a resemblance between them as to leave no doubt of their identity. It seems to be rather a variable shell, and the Cambridge specimen belongs to one of the more elongated forms. The casts of the Gasteropoda are not at all easy to identify, and there are several species of so-called *Rostellariæ* still undetermined.

FUSUS QUINQUECOSTATUS, Seeley.

Fusus quinquecostatus, Seeley, Ann. & Mag. Nat. Hist. 1861, pl. xi. f. 5.

? *Aporrhais Sanctæ-Crucis*, Pict. & Camp. pl. 92. f. 4–5.

This curious Gasteropod, which is certainly not an *Aporrhais*, but may be a *Fusus*, appears to me identical with the figures of *A. Sanctæ-Crucis* from the Aptien of Sainte-Croix; the general characters are quite the same, and the five spiral ribs so characteristic of Mr. Seeley's species are clearly delineated in the figures. Mr. Seeley's name has the priority, should they prove to be the same species.

Pterocera retusa, Sow.

Pterocera retusa, Pictet & Roux, Grès Verts, p. 263, pl. 25. f. 11.
Pterocera bicarinata, Desh.; D'Orb. Pal. Fr. pl. 208. f. 3–5; Pictet & Camp. Ste.-Croix, ii. p. 579, pl. 91. f. 5–8.

Mr. Etheridge informs me that he has no doubt that *Pt. retusa*, Sow., and *Pt. bicarinata*, Desh., are really the same species. M. Renevier (Faune de Cheville, p. 142) also considers the specimens figured under the latter name by MM. Pictet & Campiche to be the same as *Pt. retusa*, though he seems somewhat doubtful about D'Orbigny's *Pt. bicarinata*.

A well-marked cast exists in the Woodwardian Museum, which closely corresponds to those figured from Sainte-Croix.

Fusus Smithii (Sow.), Pict. and Camp. Pl. XIV. figs. 4–6.

Pyrula Smithii, Sow. Geol. Trans. iv. p. 336, pl. xi. f. 15.
? *Fusus Clementinus*, D'Orb. pl. 223. f. 8–9; Pict. & Camp. Ste.-Croix, p. 640, pl. 95. f. 4, 5.

Sowerby distinctly says this shell is not the same as his *Murex Smithii* of the Min. Conch., which has subsequently been transferred to the genus *Pyrula*, and caused confusion with the present species. Perceiving this, Mr. Seeley, in Ann. & Mag. Nat. Hist. 1861, proposed the name of *P. Sowerbyi*; but this step is unnecessary, unless the shell is truly a *Pyrula*; it has, however, been recognized as *Fusus Smithii* by MM. Pictet and Campiche ('Ste.-Croix,' summary of the genus *Fusus*), who remark that it has nearly the same shape as *F. Clementinus*, D'Orb., but differs by having more numerous ribs. Whether this difference is sufficient to make it a separate species, especially as the Cambridge specimens vary in this respect, I am inclined to doubt, and should not be surprised if, when a considerable series of specimens come to be compared, they should be found to pass into one another. Mr. Price possesses two specimens of *F. Clementinus* from the Lower Gault of Folkestone.

Natica Clementina, D'Orb.

Natica Clementina, D'Orb. Terr. Crét. ii. p. 154, pl. 172. f. 4.
Natica ervyna, Pict. & Roux, Gr. Verts, pl. 17. f. 2 (non D'Orb.?).
Turbo rotundatus, Sow. Min. Conch. pl. 433. f. 2.

M. Renevier has worked out the above synonymy and published it in a note contributed to the Société Vaudoise des Sciences Naturelles for 1856. He comes to the conclusion that the *N. ervyna* of Pict. & Roux, but not D'Orbigny's original figure, is identical with *N. Clementina*, which, again, he believes to be the shell named *Turbo rotundatus* by Sowerby. He therefore calls the shell *Natica rotundata*; but this leads to such confusion with *N. lævigata*, Desh., which Forbes called *N. rotundata*, thinking it was Sowerby's *Turbo rotundatus*, that it appears better to drop Sowerby's name altogether, and take D'Orbigny's, by which the species is best known. It is characteristic of Lower Gault, and is very rare at Cambridge.

NATICA GAULTINA, D'Orb.

Natica gaultina, D'Orb. Pal. Fr. p. 156, pl. 173. f. 3 & 4; Pictet & Roux, Grès Verts, pl. 18. f. 1.

Natica truncata, Grès Verts, pl. 18. f. 2.

N. canaliculata, Sow. Geol. Trans. iv. pl. xi. f. 12.

This species is by no means common near Cambridge, though many individuals have been found, and three fine specimens are in the possession of Mr. A. F. Buxton, of Trinity College. At Folkestone it is common both in Lower and Upper Gault. It is certainly the *N. canaliculata* of Sowerby; and I agree with M. Renevier in seeing little difference between it and the *N. truncata* of Pictet and Roux. The obliquely elongated body-whorl characterizes both, as well as the depression of the upper whorls.

NATICA RAULINIANA ?, D'Orb.

Natica Rauliniana ?, D'Orb. Pal. Fr. p. 160, pl. 174. f. 4; Pict. & Roux, Grès Verts, p. 183, pl. 18. f. 2.

Another *Natica* of about the same size as *N. gaultina*, but more compact and globose in shape, and with a more elevated spire, also occurs in the Cambridge deposit. Mr. Seeley has referred it to *N. Matheroniana*, D'Orb.; but I cannot observe much likeness between D'Orbigny's figure and the specimens in the Woodwardian Museum.

It comes nearer to *N. Rauliniana*, D'Orb.; but even this is rather more elongated than our casts, which not improbably belong to an undescribed species. Until comparison with foreign specimens shall enable me to decide upon this point, I have thought it best to retain the Cambridge casts under *N. Rauliniana,* to which they certainly bear considerable resemblance (see D'Orbigny, ii. p. 160).

LITTORINA (?) CREBRICOSTATA, Seeley. Pl. XIV. figs. 10, 11.

This pretty little shell is so named in the Woodwardian Museum; but I am not aware that Mr. Seeley has ever described or figured it.

The cast is of an elongated turbinoid shape, consisting of five rounded whorls ornamented with faint ribs, thickly set and most strongly marked on the upper part of each whorl; the section of the whorl is nearly round. In height it averages 6 lines; and the base measures $\frac{3}{8}$ of an inch. It is more like *Trochus* than *Littorina*; but I adopt Mr. Seeley's name.

TROCHUS TOLLOTIANUS, Pict. & Roux. Pl. XIV. figs. 7–9.

Trochus Tollotianus, Pict. & Roux, Grès Verts, p. 203, pl. 19. f. 9; Pict. & Camp. Ste.-Croix, ii. p. 529.

? *T. cancellatus* (partim), Seeley, Ann. & Mag. Nat. Hist. 1861, vol. vii. pl. xi. p. 15.

Pictet and Campiche speak of casts from Cambridge similar to their specimens of this shell; I can only suppose these to be one of the forms of *Trochus cancellatus*, Seeley, which vary rather in shape and amount of angulation. Neither MM. Pictet and Roux's figure, nor those of Mr. Seeley are very good; and I have therefore thought it best to figure some well-marked casts. The two chief features of the Cambridge specimens are the well-defined spiral lines, four or five on a whorl, and the occasional varices marking the position of former mouths; while Pictet and Roux describe the cast as smooth, though they speak of the shell as cancellated. A comparison with the foreign forms only will decide the question; and this I have not yet been able to make.

SOLARIUM SEDGWICKII, Seeley.

Solarium Sedgwickii, Seeley, Ann. & Mag. Nat. Hist. 1861, vol. vii. pl. xi. f. 10.

The *Solaria* of the Gault present great difficulties in their determination, so much so that Mr. Price and Mr. Newton, of Jermyn Street, who have paid some attention to the subject, are inclined to believe that all those of the "*ornatum*" type pass into one another. The margin of *S. dentatum* is sometimes produced into spines; and sometimes the dentations are hardly visible, thus passing into *S. Rochatianum* or *S. ornatum*; the ornamentation of the shell also is just as variable. *S. Sedgwickii* seems to present another link; for Mr. Seeley describes it as having "the inflated form of *S. cirroide* and the angular margin of *S. dentatum*."

M. Renevier can see little difference between *S. cirroide* and *S. Rochatianum* ('Faune de Cheville,' p. 133); and certainly the latter, as figured by MM. Pictet and Roux ('Grès Verts,' pl. 20), only appears to be a small variety of the former.

I am therefore strongly disposed to coincide in the above-mentioned view, and to regard all these so-called species as only varietal forms of one species, to which the original name of "*ornatum*" might well be applied.

PLEUROTOMARIA GIBBSII, Sow.

Pleurotomaria Gibbsii, Pict. & Camp. Ste.-Croix, ii. p. 441.

Pleurotomaria gurgitis, D'Orb. Pal. Fr. ii. pl. 192. f. 4–6; Pict. & Roux, Grès Verts, p. 237, pl. 23. f. 2.

The cast of this species has the umbilical face rather inflated, and the whorls flat or slightly convex.

Mr. Price finds it at Folkestone, both in Upper and Lower Gault; but no one has noted its occurrence at Cambridge except M. Renevier, in his 'Faune de Cheville,' p. 137, who also records the three following species from the same locality.

PLEUROTOMARIA VRACONNENSIS, Pict. & Camp.

Pleurotomaria vraconnensis, Pict. & Camp. Ste.-Croix, ii. p. 443, pl. 81. f. 3.

These casts are of rather large size, with a flat umbilical face, producing a well-marked keel; the sinus-band leaves a distinct spiral rib on the middle of the whorls. I think this is the shell which Mr. Seeley entered as *P. neocomiensis* in the list appended to one of his papers in Ann. & Mag. Nat. Hist. 1861; the two species have many features in common.

PLEUROTOMARIA ROUXI, D'Orb.

Pleurotomaria Rouxi, Pict. & Camp. Ste.-Croix, ii. p. 453, pl. 81. f. 3; Renevier, Faune de Chev. p. 140, pl. 6. f. 10, 11.

Pleurotomaria Fittoni, Pict. & Roux. (non Röm.) Gr. Verts, p. 244.

M. Renevier possesses a specimen from Cambridge which still retains a portion of the smooth shell which characterizes this species; casts closely agreeing with his description and figures are very common, those now before me being very depressed, especially in the earlier whorls, which are flattened above, slightly keeled, and rounded below; four or five whorls are usually visible.

PLEUROTOMARIA RHODANI, Brong.

Pleurotomaria Rhodani, Brong. Pict. & Roux, Grès Verts, p. 242, pl. 24. f. 1.

This species has three or four rounded whorls, with a rather more elevated spire than *P. Rouxi*, the angle varying from 105° to 125°, while the latter forms a convex angle of 140° to 160°. It is very common at Cambridge, and has also been recorded from the Upper Greensand of Hants.

CREPIDULA ? COOKSONIÆ, Seeley.

Crepidula Cooksoniæ, Seeley, Ann. Mag. Nat. Hist. 1861, vol. vii. pl. xi. f. 18.

Calyptræa Sanctæ-Crucis, Pict. & Camp. 1864, Ste.-Croix, pl. 97. f. 5–8.

Any one who compares the specimens of the above shell in the Woodwardian Museum with the figures in Pictet and Campiche, can hardly fail to recognize them as belonging to the same species, notwithstanding the difference of generic name. The cast is easily recognized by the mark of the shelly partition, which has the shape of two S-curves meeting to form a pinched-up bracket; this appears to indicate closer relations with *Calyptræa* than with *Crepidula*. It is a rare fossil, but is sometimes found inside the last chamber of large Ammonites and Hamites.

CREPIDULA GAULTINA, Buv. Pl. XIV. figs. 12, 13.

Crepidula gaultina, 1852, Pict. & Camp. Ste.-Croix, pl. 97. f. 3, 4.

Crepidula conica, Seeley, MS. ?

? *Galericulus altus*, Seeley, Ann. & Mag. Nat. Hist. 1861, vol. vii. pl. xi. f. 19.

The specimen named *C. conica* in the Woodwardian Museum appears to me identical with the *C. gaultina* of Buvignier, which is found, though rarely, in the "Gault supérieur" of St. Croix. The mark of the shelly partition takes the form of two straight furrows diverging from a point just below the apex.

The small shell, named *Galericulus altus* by Mr. Seeley, in Ann. & Mag. Nat. Hist. vol. vii. 1861, p. 12, and of which only one specimen exists, may not improbably turn out to be an elevated form of *Crepidula gaultina*; the generic name is founded on the supposed presence of a second septum directed upwards; but more specimens must be found before it can be proved that the indentation on the cast is not the result of an accidental growth. Its unsymmetrical position makes this at least possible.

DENTALIUM DECUSSATUM, Sow.

Dentalium decussatum, Sow. Min. Conch. pl. 70. f. 5.
Dentalium ellipticum, Sow. ibid. pl. 70. f. 6.

The casts of these two forms, so well known from the Folkestone Gault, are perfectly undistinguishable; but the shell of *D. ellipticum* is thicker across one diameter than the other, thus giving the section an elliptical shape. Mr. Price considers, however, that this is merely a varietal difference; and Mr. Etheridge is inclined to agree with him. It is one of the commonest fossils at Cambridge, occurring everywhere, but always in the condition of black casts.

LAMELLIBRANCHIATA.

OSTREA FRONS, Park.

Ostrea frons, Park. Org. Rem. pl. xv. f. 4.
Ostrea carinata, Sow. (pars), Min. Conch. pl. 365. f. 1–3.
Ostrea Milletiana, D'Orb. Pal. Fr. iii. pl. 472. f. 5–7; Pict. & Camp. Ste.-Croix, p. 309, pl. 194. f. 7–9.

This fossil ranges from the Upper Gault at Folkestone, where it has recently been found, to the Grey Chalk of the same locality. It is common in the Cambridge bed, some specimens being much waterworn and containing a phosphatic cast, while others are well preserved and only filled with sandy marl, in which small phosphatic nodules are sometimes imbedded. Their condition, therefore, is perfectly consistent with their range, some having been derived, and others having lived during the deposition of the bed. M. Renevier finds it in the "Gault supérieur" of Cheville, and remarks that some of his specimens from Cambridge show a slight transition towards the true *O. carinata*; these forms have, I believe, gone under the name of *O. macroptera* at Cambridge. MM. Pictet and Campiche discuss the relations of *O. Milletiana* at p. 310 of their monograph.

OSTREA VESICULARIS, Lam.

Ostrea vesicularis, D'Orb. Pal. Fr. p. 742, pl. 487.
Chama canaliculata, Sow. Min. Conch. pl. 26. f. 1.
Ostrea canaliculata, D'Orb. Pal. Fr. p. 709, pl. 471. f. 4–8; Pict. & Camp. Ste.-Croix, p. 305, pl. 193. f. 4–14.

Mr. Etheridge agrees with me in thinking that the same shell has been described under two different names according to the formation in which it was found; it seems generally to have been called *O. canaliculata* when obtained from the Gault (see D'Orbigny, *loc. cit.*), and *O. vesicularis* when found in Greensand and Chalk.

A comparison of the figures of the two species above cited will disclose how little difference there is between them; and a study of the fossils themselves results in finding the same series of forms in the Gault as in the Chalk-marl; so variable is the shell according to its position and opportunities of growth.

It must not, however, be confounded with Sowerby's *Ostrea canaliculata* (Min. Conch. ii. pl. 135. f. 1), an elongated and slightly carinated species, which Mr. Etheridge thinks is probably the same as *Ostrea larva* (Lam. Anim. sans Vert. vi. p. 216).

O. vesicularis is a very common shell in the Cambridge nodule-bed, and occurs, as its range would indicate, both as a cast and as a shell, the latter being frequently attached to nodules and boulders.

EXOGYRA HALIOTOIDEA, Sow.

Chama (*Exogyra*) *haliotoidea*, Sow. Min. Conch. i. p. 67, pl. 25; D'Orb. Pal. Fr. pl. 478. f. 1–4.

Exogyra Rauliniana, D'Orb. Pal. Fr. p. 708, pl. 471. f. 1–3; Pict. & Camp. Ste.-Croix, pl. 193. f. 15, 16.

This species has not before been cited from Cambridge; but I possess specimens of very typical form, besides others, undistinguishable from those so named in the Hunstanton Limestone, which more closely approach the types of *E. Rauliniana* in shape. Specimens undoubtedly belonging to the latter are common at Cambridge; and I was glad to find, on consulting Mr. Etheridge, that he fully believes them to be only varieties of the same species; the larger and narrower varieties, usually called *E. Rauliniana*, are, perhaps, more common in Gault, and wider forms in the higher beds; but the shape of individuals is so entirely determined by their position of growth that no certain rule is followed. Their favourite station seems to have been upon *Ammonites rostratus*; and they frequently bear a perfect cast of the shell on which they grew.

LIMA ELONGATA, Sow.

Lima elongata, Sow. Min. Conch. pl. 559. f. 2.

Lima Itieriana, Pict. & Roux, p. 484, pl. 40. f. 5; Pict. and Camp. pl. 166. f. 4, 5.

This species, which has often been confused with *L. parallela*, Sow., is the subject of a long discussion by MM. Pictet and Campiche, who finally decide upon abandoning both of Sowerby's names, on the plea of insufficient description and delineation. They range the fossils which have been referred to these species under two heads —*Lima Cottaldina*, D'Orb., for the Aptian and Lower Greensand species, and *L. Itieriana*, Pict. and Roux, for the Gault species; and they are inclined to regard *L. parallela* of D'Orbigny as distinct from either. Sowerby's figure of *Modiola parallela* (M. C. pl. 9. f. 1) is certainly unrecognizable; but I see no reason why his *Plagiostoma elongata* should not be retained, since its characters are apparent and similar to those of *L. Itieriana*; this is the course adopted by Prof. Renevier in the 'Faune de Cheville,' p. 162.

? HINNITES STUDERI, Pict. & Roux.

? *Hinnites Studeri*, Pict. & Roux, Grès Verts, p. 504, pl. 45. f. 1; Pict. & Camp. Ste.-Croix, pl. 179.

There are three species of *Hinnites* in the Woodwardian Museum: two of these have been named respectively *H. trilinearis* and *H. pectinatus* by Mr. Seeley; the third is unnamed, but closely corresponds with the figures and descriptions of *H. Studeri* from the "Gault supérieur." It appears to differ from *H. trilinearis* by wanting the striæ on the ribs, which are also more numerous, and have striated interspaces; the flat attached valve is more finely ribbed.

PLICATULA PECTINOIDES, Sow.

Plicatula pectinoides, Sow. Min. Conch. pl. 409. f. 1.
Plicatula gurgitis, Pict. & Roux, Grès Verts, pl. 47. f. 4.
Plicatula radiola, Grès Verts, pl. 47. f. 3; D'Orb. Pal. Fr. pl. 463. f. 1–7.
Plicatula inflata, Min. Conch. pl. 409. f. 2.

There can be no doubt, I think, that MM. Pictet and Campiche are right in considering *P. gurgitis* and *P. pectinoides* to be the same species. Mr. Etheridge is also inclined to think that *P. radiola* is only another form of the same. The variety, *P. inflata*, is a Chalk-marl form; and the few specimens I have seen among the Cambridge nodules have all been in soft light-coloured phosphate. The true *P. pectinoides* is characteristic of the Gault, and very common at Cambridge in the state of a dark phosphate cast covered by the more or less waterworn shell.

SPONDYLUS GIBBOSUS, D'Orb.

Spondylus gibbosus, D'Orb. Pal. Fr. iii. p. 658, pl. 452. f. 1–6.
Spondylus Brunneri, Pict. & Roux (pars), p. 516, pl. 42. f. 2.

This species is not acknowledged in the Woodwardian Museum; but Mr. Seeley speaks of its occurrence at Cambridge, in the Ann. & Mag. Nat. Hist. 1866, vol. xvii. p. 177; and there can be no doubt that most of those which have passed under the name of *S. truncatus* belong really to this last Gault form. It is characterized by the gibbose shape of the umbones and general irregularity of the shell. There are some *Spondyli*, however, which belong to the Chalk-marl itself; and their attached lower valves are common on the casts, nodules, and boulders in the bed; these may be *S. truncatus*, but more probably *S. striatus*.

? SPONDYLUS DUTEMPLEANUS, D'Orb.

? *Spondylus Dutempleanus*, D'Orb. Pal. Fr. iii. p. 672, pl. 460. f. 6–11.

There is another species of *Spondylus* at Cambridge with slightly spiny valves, which Mr. Seeley has named *S. hystrix*, though there is one specimen which he has marked *S. Dutempleanus*. If distinct from *S. gibbosus*, I should be inclined to refer them all to the latter species; several of them closely resemble M. d'Orbigny's figures, while *S. hystrix* is a much larger and more regular shell. Neither is a Gault form; but the Cambridge specimens are generally filled with dark phosphate, and appear to be derived*.

AVICULA GRYPHÆOIDES, Sow.

Avicula gryphæoides, Sow. Geol. Trans. iv. pl. ix. f. 3.

Inoceramus Coquandianus, D'Orb. Pal. Fr. pl. 403. f. 6–8; Pict. & Camp. Ste.-Croix, pl. 160. f. 9, 10.

This shell, although simulating *Inoceramus* in form, has a notch below the ear of the left valve and only one cartilage-pit; it was rightly referred therefore to the genus *Avicula*, and probably falls under the subgenus *Aucella*. It is not the *Inoceramus gryphæoides* of Min. Conch. pl. 584. f. 1, which I agree with D'Orbigny in considering to be only a variety of *I. concentricus*, Sow. (see also Pict. & Camp. Ste.-Croix, part iv. p. 119).

A. gryphæoides ranges from Upper Gault to Chalk-marl; it occurs in the topmost bed of the Gault, both in Bedfordshire and Folkestone, and is quite as abundant in the Chalk-marl of Cambridge and Beds. With this range the fossils in the Cambridge Greensand perfectly agree, the delicate shell being often preserved before passing through the mill, and the bare cast being likewise very common.

At Barton, near the termination of the nodule-bed, this shell is very abundant, being mostly derived, I believe, from a bed of dark sandy Gault immediately underlying the Chalk-marl at Toddington; others, however, have certainly lived while the nodules were being drifted into their present position. It appears therefore in both lists.

INOCERAMUS SULCATUS, Park.

Inoceramus sulcatus, D'Orb. Pal. Fr. iii. pl. 403. f. 3–5; Pict. & Roux, Grès Verts, pl. 42. f. 1.

A small fragment, probably belonging to this species, was figured by Mr. Seeley in the Ann. & Mag. Nat. Hist. for 1861, vol. vii. pl. 6. f. 3, under the name of *Arca sulcata*. In a later volume of the same Magazine, however (1866, vol. xvii. p. 178), he himself suggests the possibility of its being really the apex of *Inoceramus sulcatus*. I entertain little doubt of this being actually the case; but I am not aware that any other fragments have since been found, except a large specimen in the Museum, the "gisement" of which is somewhat doubtful.

It is certainly remarkable that a shell so characteristic of the lower part of the Upper Gault at Folkestone should be nearly absent in the more northern counties; but I have never seen a specimen in Bucks, Beds, or Cambridge, except at Ely, where a few specimens have been found. The partial occurrence of this shell is also recorded by M. Renevier ('Faune de Cheville,' p. 101); he says, "It is singular that this *Inoceramus*, so common at the Perte du Rhône, should be so rare at Cheville, and in general among Alpine localities."

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* I much doubt, however, their distinctness from *S. gibbosus*. The spiny valve closely resembles fig. 3 of MM. Pictet and Campiche; and intermediate forms are found among the Cambridge specimens.

INOCERAMUS CONCENTRICUS, Park.

Inoceramus concentricus, D'Orb. Pal. Fr. p. 506, pl. 404; Pict. & Roux, Grès Verts, pl. 42. f. 2.

Three specimens of what is probably a large variety of this shell are preserved in the Woodwardian Museum; and others are in the possession of Mr. J. Carter, M.R.C.S., and of Mr. A. F. Buxton, Trinity College. The rarity of this species at Cambridge must, I suppose, be accounted for in the same way as that of its congener, *I. sulcatus*. It is not to my knowledge found in the Upper Gault of Bucks.

ARCA HUGARDIANA, D'Orb.

Arca Hugardiana, Pal. Fr. p. 216, pl. 313. f. 4–6; Pict. & Roux, Grès Verts, p. 457, pl. 36. f. 1; Pict. & Camp. Ste.-Croix, iii. p. 560.

The shells or, rather, casts which I regard as belonging to this species, have been considered by Mr. Seeley to be a "dwarf race" of *Arca irregularis*, D'Orb.; but a careful comparison of those in the Woodwardian Museum has led me to differ from this identification and to refer them to *Arca Hugardiana*, D'Orb. In this conclusion Mr. Price fully agrees with me, and considers that the little *Arca* which is not uncommon in the Upper Gault of Folkestone belongs to the same species.

NUCULA BIVIRGATA, Sow. Pl. XV. f. 4–8.

Nucula bivirgata, Sow. Geol. Trans. ser. 2, vol. iv. pl. xi. f. 8; D'Orb. Pal. Fr. pl. 303. f. 1–7.

Among the species of *Nucula* which have been found in the Cambridge nodule-bed, one is by far the commonest, and has been identified by Mr. Seeley with *N. simplex*, Desh., a Neocomian species. I regret that I must again differ from that gentleman, having come to the conclusion that these well-marked casts are those of *N. bivirgata*, a characteristic species of the Gault. I was for some time uncertain to what species they belonged, but was rather inclined to consider them young forms of *N. pectinata*, Sow. I found also that MM. Pictet and Campiche (Ste.-Croix, iii. p. 414) give the "Grès vert de Cambridge (?)" as a locality for that fossil. On consulting Mr. Price about them he told me that similar casts had often been found in the Folkestone Gault, but that he was not certain about their identification. He very kindly allowed me, however, to take specimens of both *N. pectinata* and *N. bivirgata* out of his collection, and to remove their shells, in order to compare the casts with the Cambridge forms. The result was that the cast of *N. bivirgata* proved to be of the same shape and proportions; and we were satisfied that the doubtful forms belonged to that species. The presence of a specimen in the Woodwardian Museum retaining the phosphatized shell confirms this conclusion.

I have since repeated the operation on other specimens from Folkestone, and with the same satisfactory result, disclosing, moreover, the existence of two varieties, one shorter and more triangular than the form figured by M. D'Orbigny; both occur at Cambridge, and are figured on Pl. XV. f. 4–6.

Isoarca Agassizii, Pict. & Roux. Pl. XV. figs. 1–3.

Isoarca Agassizii, Pict. & Roux, Grès Verts, p. 446, pl. 38. f. 3.

This shell is very rare at Cambridge; but there are fortunately five good specimens in the University collection, all of them casts in dark phosphate, four of which agree closely with the figures of MM. Pictet and Roux. The fifth is a smaller variety, with less-inflated umbones. Mr. Seeley has, I believe, given these fossils the MS. name of *I. cantabrigiensis*; but I see no reason for separating them from the above species, especially as the shell of the Cambridge specimens is not yet known.

Lucina tenera, Sow. Pl. XV. figs. 10–12.

Venus tenera, Sow. Geol. Trans. ser. 2. vol. iv. pl. xi. f. 7.

A single specimen of this shell is in the Woodwardian Museum; and I have seen two other individuals. They are all black casts, but well marked, and precisely similar to the casts and shells common in one particular bed of the Folkestone Gault: this is Bed II. in the Lower Gault of Mr. Price, and he tells me that the shell is not found there at any other horizon. It is therefore characteristic of the Lower Gault.

Corbis gaultina, Pictet. Pl. XV. fig. 9.

Fimbria gaultina, Pictet; Pict. & Camp. Ste.-Croix, iii. pl. 122. f. 3, 4; Pict. & Roux, Grès Verts, pl. 34. f. 4.

There are two nearly perfect casts in the Woodwardian Museum, which I am inclined to refer to the above species. The undulated growth of the shell leaves concentric markings upon the casts, which closely resemble the figures mentioned above; but I have not been able to see the specimens themselves. The species is found in the Alpine Gault and the Vraconnian of Ste.-Croix and Cheville.

Pholadomya decussata, Phill.

Cardium decussatum, Fitton, Geol. Trans. vol. vi. p. 113.
Pholadomya decussata, var. *triangulata,* Seeley, Ann. & Mag. Nat. Hist. 1861, vol. vii. p. 122.

These casts are rather dwarfed varieties of the Chalk form, but agree with it in all essential characters; they are seldom met with near Cambridge, and are rarely in good preservation. The *Cardium decussatum* of Sowerby, described originally from the Chalk-marl, is cited by Dr. Fitton as having been also obtained from Copt Point near Folkestone; so that the shell ranges from Gault to Chalk; and the Cambridge specimens are clearly derived from the former deposit, being waterworn casts in black phosphate.

BRACHIOPODA.

TEREBRATULA BIPLICATA, Sow. (non Brocchi).

Terebratala biplicata, Sow.; Davidson, Cret. Brach. p. 55. pl. 6.
T. Dutempleana, D'Orb. Pal. Fr. iv. p. 93, pl. 511. f. 1–8; Pict. & Roux, pl. 51. f. 1–4.

The varieties figured by Mr. Davidson as *Dutempleana* and *obtusa* are very common near Cambridge, though I have also seen deeply plicated forms which closely approach the typical *T. biplicata*. The casts are sometimes dark, but more often of a lighter buff colour and preserving the shell; many of these specimens probably come from the sandy beds at the top of the Gault, though some belong to the Chalk-marl itself. *T. Dutempleana* is not unfrequent in the Upper Gault of Folkestone, but has never been found below Bed VII. of Mr. Price's section.

The three forms above mentioned are indicated by M. Renevier as occurring in the Vraconnian at Cheville; and, lastly, they are common in the "Gault friable" at Esa near Nice, where they occur in the same phosphatic condition as at Cambridge.

RHYNCHONELLA SULCATA, Park.

Rhynchonella sulcata, Park. Geol. Trans. vol. v. p. 59; Davidson, Cret. Brach. pl. 10. f. 18–36.
Rhynchonella Emerici, Pict. & Roux (non D'Orb.), pl. 50. f. 6.

This species, which is so common at Cambridge in the same state of preservation as *Terebratula biplicata*, has never yet been found for certain in the English Gault or Upper Greensand; it is, however, moderately abundant in the Vraconnian or "Gault supérieur" of Cheville, but is not known at Ste.-Croix; Mr. Davidson, again, has collected it at Esa in the same bed with *Terebratula biplicata* and *Kingena lima*. *Rhynchonella sulcata* therefore appears to have been a species of very partial distribution, having perhaps existed in colonies where conditions were favourable to it.

RHYNCHONELLA LATISSIMA (J. Sow.), Dav.

Rhynchonella latissima, Davidson, Cret. Brach. xi. f. 6–22.
Rhynchonella lata, Pict. & Roux, p. 530, pl. 50. f. 3, 4.

Casts of a similar type to the Warminster shells are occasionally found in the nodule-bed, always in brown phosphate, but are by no means common. They occur likewise at Cheville and La Perte du Rhône. They would seem here to have lived in the Upper Gault period.

RHYNCHONELLA COMPRESSA, Lam.

Rhynchonella compressa, Lam.; D'Orb. Pal. Fr. iv. p. 35, pl. 497. f. 1–6. Darw. Cret. Brach. xi. f. 1–5.

Of this species, which is much wider (!) than the accredited "*latis-*

sima," there is one specimen in the Woodwardian Museum. This and the preceding are the only characteristic Warminster species that occur at Cambridge.

ECHINODERMATA.

CIDARIS GAULTINA, Forbes. Pl. XV. figs. 13, 14.

Cidaris gaultina, Forbes, Mem. Geol. Surv. Dec. v. Suppl. to pl. v. p. 2; Pal. Soc. 1864, p. 36, pl. i. f. 2–4.

A fine cast, retaining a portion of the shell in a phosphatized condition, and two other less perfect specimens apparently belonging to this species are in the collection of the University. Mr. Price recognizes them as similar to those found in the Upper Gault of Folkestone. The first mentioned is figured at Pl. XV. f. 13, and measures 20 lines in diameter, with a height of 16 lines. Fig. 14 is a segment from the Upper Gault of Folkestone in Mr. Price's collection, not so much crushed as that figured in the Pal. Soc., which did not admit of measurement.

PSEUDODIADEMA CARTERI, Woodw. Pl. XV. figs. 15–17.

Diadema Carteri, Woodw. Mem. Geol. Surv. Dec. v. pl. ii. p. 9.

The type specimens of this species in the Woodwardian Museum appear to me very different from *P. ornatum*, to which Dr. Wright has referred it. They are much smaller and higher in proportion, having a width of 10 lines, and an altitude of 6, according to Dr. Woodward; the ambulacral tubercles become rapidly smaller above; the secondary tubercles are few, whereas in *P. ornatum* they extend from the peristome nearly to the disk; lastly, the space between the interambulacral tubercles is strongly granulated. Mr. Seeley has described four more species, two of which, *P. scriptum* and *P. inversum*, much more closely resemble *P. ornatum*, and have in fact been so named in the Museum at Jermyn Street. I cannot help thinking there has been some confusion in the specimens which were submitted to Dr. Wright, and that he has not seen the original types of *P. Carteri*. I have therefore figured two of these on Pl. XV. f. 13–15.

CRUSTACEA.

DIAULAX CARTERIANA, Bell.

Diaulax Carteriana, Bell, Pal. Soc. Cret. Crust. pl. i. f. 14–16.

This small Crustacean has recently been obtained from the Folkestone Upper Gault, adding therefore another link between that formation and the Cambridge bed from which it was originally described. Four or five have been found in Bed XI. by the indefatigable fossil-collector, Mr. Griffiths; one of these, not quite perfect, is now in the Woodwardian Museum, which also possesses specimens of *Necrocarcinus Woodwardi* and *N. tricarinatus* from the Lower Gault.

ACTINOZOA.

TROCHOCYATHUS CONULUS, Edw. (non Phill.). Pl. XIV. figs. 14–16.

Trochocyathus conulus, Edw. & Haime, Pal. Soc. Foss. Corals, i. p. 63, pl. 11. f. 5.

Smilotrochus elongatus, Duncan, Cret. Corals, pl. 9. f. 1–4, pl. 12. f. 10–16, pl. 14. f. 13–15.

In the absence of any distinctive characters beyond the supposed want of an epitheca and columella in the latter, I could not help regarding these two corals as of doubtful distinctness even as species. Moreover MM. Edwards and Haime state that their types of *T. conulus* were collected in the neighbourhood of Cambridge; they must therefore have been what Prof. Duncan has since called *Smilotrochus elongatus.*

Again, there are in the Woodwardian Museum, and elsewhere, certain specimens which show the base of attachment, and apparently possess an epitheca; these would, I suppose, be called *T. conulus*; yet the upper part, from which the epitheca has been removed, shows the ordinary characters of *Sm. elongatus.*

M. Renevier (p. 176) mentions the common occurrence of *T. conulus* at Cheville, and says that some are "munis de leur test," but that most are only casts, agreeing perfectly with his types from Cambridge and from la Perte du Rhône. These, of course, being casts, have no columella; but a section often shows the space it originally occupied *.

I submit, therefore, that the Cambridge corals are nothing but casts of *T. conulus,* from which not only the delicate epitheca, but the whole corallum has in most cases been completely worn away, and that the name of *Smilotrochus elongatus* is unnecessary; MM. Edwards and Haime, however, at p. 65 of their Monograph, state that the fossil designated by Phillips under the name of *Turbinolia conulus* was found at Speeton; and Mr. Etheridge is of opinion that this is not the same species as the *Trochocyathus conulus* from Cambridge. In designating these forms, therefore, M. Edwards's name, and not that of Phillips, must be appended to the species.

TROCHOCYATHUS HARVEYANUS, Edw. & Haime.

Trochocyathus Harveyauus, Pal. Soc. Foss. Corals, pl. xi. f. 4; Duncan, Cret. Corals, pl. xii. f. 1–4, pl. xiii. f. 1–4, pl. xiv. f. 1–5.

This is not an uncommon fossil in the Cambridge bed, though no one has yet recognized it as belonging to the above species, the reason probably being, as in the case of *T. conulus,* the different

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* I also possess a longitudinal section disclosing the columella itself, as well as the partially preserved septa, which end abruptly against it; the specimen is figured on Plate XIV., together with one showing epitheca.

appearance presented by the coral in the state of a cast without corallum and epitheca. The Cambridge specimens, being casts of the calyx, are sometimes nearly flat below, while in perfect specimens of *T. Harveyanus* the corallum forms a somewhat conical base.

When, however, I found that precisely similar casts existed in the Folkestone Gault, and that Mr. Price had always considered them to belong to *T. Harveyanus,* I had no hesitation in referring them to the same species, in which step Mr. Etheridge also fully concurs.

At Folkestone Mr. Price has not yet found it above the Lower Gault, though it is abundant in the top beds, Nos. VI. and VII., which also contain many of the other Lower-Gault forms occurring at Cambridge.

Another species, *Smilotrochus* (? *Trochocyathus*) *angulatus,* Duncan, is very common in the nodule-bed, but is only found in the very lowest bed at Folkestone; in Cambridgeshire therefore it must have had a much higher range; and it occurs in the nodule-bed of Bucks.

The following list of Cambridge fossils is compiled almost entirely from the collection in the Woodwardian Museum, and may in fact be taken as a catalogue of that collection. The lists of Reptilia are simply taken, with but little alteration, from Mr. Seeley's 'Index to the Woodwardian Collection;' but the Mollusca have been subjected to a thorough revision.

As regards the tables of range, the first two columns, showing the horizon of Gault fossils, are filled up chiefly from those appended to Mr. Price's paper on the Gault of Folkestone (Quart. Journ. Geol. Soc. vol. xxx.), supplemented by my own observations and further identifications of species among Mr. Price's valuable collection.

For the table of "Gault-supérieur" or Vraconnian fossils, I have consulted MM. Pictet and Campiche's Monograph on the Environs de Ste.-Croix; "La Faune de Cheville," by Prof. Renevier (Soc. Vaudoise des Sc. Nat. ix. pp. 105 & 389); and "Les Environs de la Perte du Rhône" (Soc. Helv. des Sc. Nat. 1855, vol. xiv.), by Prof. Renevier.

For the Greensands my authorities are Phillips's 'Geology of Oxford,' the Memoirs of the Geological Survey, and the collections in the Woodwardian Museum. The last column is filled in from the fossils in the Woodwardian Museum and in Mr. Price's collection, and from the Survey Memoirs, Bristow's 'Isle of Wight,' &c.

§ 5. *List of Fossils from Cambridge Greensand.*

Part I.—Fauna derived from the Gault.

Gault Fauna.	Lower Gault.	Upper Gault.	Vraconnian (Cheville &c.).	Upper Greensand.	Warminster-beds.	Chalk-marl and Grey Chalk.
REPTILIA.						
Ichthyosaurus campylodon, *Carter*	*	*	......	......	......	*
—— platymerus, *Seeley*.						
—— Bonneyi, *Seeley*.						
—— Walkeri, *Seeley*.						
—— Doughtyi, *Seeley*.						
Plesiosaurus planus, *Owen*	......	*?				
—— latispinus, *Owen*.						
—— neocomiensis, *Camp*.						
—— constrictus, *Owen*	......	......	......	......	......	*
—— euryspondylus, *Seeley*.						
—— platydeirus, *Seeley*.						
—— ophiodeirus, *Seeley*.						
—— pœcilospondylus, *Seeley*.						
Polyptychodon interruptus, *Owen*	......	*	......	......	......	*
Stereosaurus cratynotus, *Seeley*.						
Acanthopholis macrocercus, *Seeley*.						
Crocodilus cantabrigiensis, *Seeley*.						
Rhinochelys mastocephalus, *Seeley*	...	Limb-bones, scapulæ, and marginal plates of species not yet described.				
—— eurycephalus, *Seeley*	...					
—— cardiocephalus, *Seeley*	...					
—— sphenocephalus, *Seeley*	...					
—— platycephalus, *Seeley*	...					
—— graptocephalus, *Seeley*	...					
—— dacognathus, *Seeley*	...					
—— dimerognathus, *Seeley*	...					
—— colognathus, *Seeley*	...					
—— leptognathus, *Seeley*	...					
—— platyrhinus, *Seeley*	...					
—— rheporhinus, *Seeley*	...					
—— grypus, *Seeley*	...					
—— Dayi, *Seeley*	...					
Trachydermochelys phlyctænus, *Seeley*.						
Ornithocheirus Sedgwicki, *Owen*.						
—— Woodwardi, *Owen*.						
—— Oweni, *Seeley*.						
—— polyodon, *Seeley*.						
—— microdon, *Seeley*.						
—— scaphorhynchus, *Seeley*.						
—— brachyrhinus, *Seeley*.						
—— crassidens, *Seeley*.						
—— dentatus, *Seeley*.						
—— nasutus, *Seeley*.						
—— tenuirostris, *Seeley*.						
—— capito, *Seeley*.						
—— eurygnathus, *Seeley*.						
—— machærorhynchus, *Seeley*.						

List of Fossils (continued).

Gault Fauna.	Lower Gault.	Upper Gault.	Vraconnien (Cheville &c.).	Upper Greensand.	Warminster-beds.	Chalk-marl and Grey Chalk.
Ornithocheirus enchorhynchus, *Seeley.*						
—— colorhinus, *Seeley.*						
—— oxyrhinus, *Seeley.*						
—— simus, *Owen.*						
—— platyrhinus, *Seeley.*						
AVES.						
Enaliornis Barretti, *Seeley.*						
—— Sedgwicki, *Seeley.*						
PISCES.						
Otodus appendiculatus, *Ag.*	*	*	*	......	*	*
Lamna subulata, *Pict. & Camp.*	......	*	*	* ?		
—— gracilis, *Ag.*	......	*	*			
Corax falcatus, *Ag.*	......	......	*	......	......	*
Saurocephalus lanciformis, *Harlan*	......	*	......	*	......	*
Pachyrhizodus glyphodus ?, *Blake*	......	*				
Hypsodon minor, *Eg.*						
Lepidotus, sp. (scales)						
Pycnodus obliquus ?, *Pict. & Camp.*	......	......	*			
——, sp. nov.						
? Cestracion canaliculatus, *Eg.*	......	......	......	......	......	*
Hybodus, sp.	......	*				
Ptychodus spectabilis, *Ag.*						
Plethodus expansus, *Dixon.*						
Sphenonchus, sp.						
Pisodus, sp.	*					
Edaphodon Sedgwicki, *Ag.*	*	*	......	......	......	*
Ischyodus Agassizii, *Eg.*	*	*				
CEPHALOPODA.						
Belemnites ultimus, *D'Orb.* (var.)	......	*	*	*	*	*
—— minimus, *Lister*	*	*	*			
Conoteuthis, sp.						
Nautilus albensis, *D'Orb.*	......	......	*			
—— Largilliertianus, *D'Orb.*	......	......	*	......	*	*
—— Clementinus, *D'Orb.*	*	*	*			
—— Montmollini ?, *Pictet*	......	.....	*			
——, sp.						
Ammonites rostratus, *Sow.*	......	*	*	*	*	
—— ——, var. inflatus, *Sow.*	......	*	*			
—— planulatus, *Sow.*	......	*	*	......	......	*
—— ——, var. Mayorianus, *D'Orb.*	......	*	*			
—— latidorsatus, *Mich.*	......	......	*			
—— Timotheanus, *Mayor*	......	......	*			
—— dispar, *D'Orb.*	......	* ?	*			
—— Woodwardi, *Seeley*	......	* ?				
—— glossonotus, *Seeley.*						
—— cœlonotus, *Seeley*	......	*	*			
—— sexangulatus, *Seeley.*						
—— ——, var. rhamnonotus, *Seeley.*						

List of Fossils (continued).

Gault Fauna.	Lower Gault.	Upper Gault.	Vraconnien (Cheville &c.).	Upper Greensand.	Warminster beds.	Chalk-marl and Grey Chalk.
Ammonites acanthonotus, *Seeley.*						
—— splendens, *Sow.*	*	*	*	......	*	
—— ——, var. leptus, *Seeley.*						
—— ——, var. cratus, *Seeley*	......	*				
—— auritus, *Sow.*	*	*	*	*	*	
—— ——, var. Salteri, *Sharpe*	......	......	......	......	......	*
—— Raulinianus, *D'Orb.*	*	*	*			
—— ——, var. tetragonus, *Seeley*	......	......	*			
—— Studeri, *Pict. & Camp.*	*	*	*			
—— vraconnensis, *Pict.*	......	......	*			
—— Renauxianus, *D'Orb.*	......	......	*	......	*	*
Scaphites Hugardianus, *D'Orb.*	......	......	*			
—— Meriani, *Pict. & Camp.*	......	......	*			
—— ——, var. simplex, mihi	......	*				
Turrilites Bergeri, *Brongn.*	......	*	*	......	*	*
—— Hugardianus, *D'Orb.*	*	......	*			
—— Puzosianus, *D'Orb.*	......	......	*			
—— Wiestii, *Sharpe*	......	......	......	......	......	*
Helicoceras Robertianum, *D'Orb.*	......	*	*			
—— 4-tuberculatum (? auct.).						
Ancyloceras tuberculatum, *Sow.*	......	*				
Anisoceras armatum, *Sow.*	......	*	*	*	......	*
—— Saussureanum, *Pictet*	......	*?	*			
Hamites intermedius, *Sow.*	*	......	*			
—— virgulatus, *Sow.*	*	......	*			
Baculites Gaudini, *Pict. & Camp.*	*	......	*			
—— baculoides ?, *Mant.*	......	......	*	*		
GASTEROPODA.						
Pterocera Fittoni, *Forbes*	*?					
—— retusa, *Sow.*	*	......	*			
—— globulata, *Seeley.*						
Rostellaria Parkinsoni, *Sow.*	*	......	*	......	*?	
—— Orbigniana, *Pict.*	*	*	*			
—— carinata, *Mant.*	*	*				
—— elongata, *Sow.*	*					
Pterodonta marginata, *Seeley.*						
—— longispira, *Seeley.*						
Buccinum gaultinum, *D'Orb.*	*					
Pyrula ? conoidea, *Seeley, MS.*						
Fusus Smithii, *Sow.*	*	......	*	*		
—— tricostatus, *Seeley.*						
—— quinquecostatus, *Seeley.*						
Scalaria angularis, *Seeley.*						
—— tenuistriata, *Seeley.*						
Cerithium mosense ?, *Buv.*	*	......	*			
——, sp.						
Nerinæa, sp.						
Natica gaultina, *D'Orb.*	*	*	*			
—— Clementina, *D'Orb.*	*	......	*			
—— Rhodani, *Pict. & Roux*	......	......	*			

List of Fossils (continued).

Gault Fauna.	Lower Gault.	Upper Gault.	Vraconnien (Cheville &c.).	Upper Greensand.	Warminster beds.	Chalk-marl and Grey Chalk.
Natica Rauliniana?, *D'Orb.*	......	......	*			
Neritopsis scalaris, *Seeley.*						
Mesochilotoma striata, *Seeley.*						
Trochus Tollotianus?, *Pict. & Roux*	......	......	*			
—— cancellatus, *Seeley.*						
Gibbula levistriata, *Seeley*	......	......	......	......	*	
Turboidea nodosa, *Seeley.*						
—— expansa, *Seeley.*						
Littorina crebricostata, *Seeley, MS.*						
Solarium ornatum, *Sow.*	*	*	*	*	*	
—— granosum, *D'Orb.*	......	......	*			
—— dentatum, *Desh.*	*	*	*			
—— Sedgwickii, *Seeley.*						
—— Rochatianum, *Pict. & Roux*	......	......	*			
—— planum, *Seeley.*						
—— Carteri, *Seeley.*						
Pleurotomaria Gibsii, *Sow.*	......	*	*			
—— Rouxi, *D'Orb.*	......	......	*			
—— Rhodani, *Brong.*	......	*	*	*		
—— vraconnensis, *Pict. & Camp.*	......	......	*			
—— allobrogensis, *Pict. & Roux*	......	......	*			
—— La Harpi, *Pict. & Camp.*	......	......	*			
—— Jukesii, *Seeley.*						
—— semiconcava, *Seeley.*						
—— lima, *D'Orb.*	......	......	*			
Avellana incrassata, *Sow.*	......	*?	*			
—— ventricosa, *Seeley*	......	......	*			
—— Hugardiana, *D'Orb.*	......	......	*			
——, sp.						
Tornatella pyrostoma, *Seeley.*						
——, sp.						
Stomatodon politus, *Seeley.*						
Acmæa tenuistriata, *Seeley.*						
Crepidula Cooksoniæ, *Seeley*	......	......	*			
—— gaultina, *Buv.*	......	*?	*			
Galericulus? altus, *Seeley.*						
Dentalium decussatum, *Sow.*	*	*	......	......	*	
LAMELLIBRANCHIATA.						
Ostrea frons, *Park.*	......	*	*	......	*	*
—— vesicularis, *Sow.*	......	*	*	*	*	*
Exogyra Rauliniana, *D'Orb.*	......	*	*			
—— conica, *Sow.*, var.	......	*	*	*	*	
Pecten orbicularis, *Sow.*	*	*	*	*	*	*
—— Barretti, *Seeley.*						
——, sp.						
Neithea quadricostata, *Sow.*	......	*	*	*	*	
—— quinquecostata, *Sow.*	*	*	*	*	*	*
Hinnites trilinearis, *Seeley*	......	*				
—— pectinatus, *Seeley.*						
—— Studeri, *Pict. & Roux*	......	*?	*			

List of Fossils (continued).

Gault Fauna.	Lower Gault.	Upper Gault.	Vraconnien (Cheville &c.).	Upper Greensand.	Warminster beds.	Chalk-marl and Grey Chalk.
Plicatula pectinoides, *Sow.*	*	*	*	*		
—— sigillina, *Woodward*	......	*	......	......	......	*
Spondylus gibbosus, *D' Orb.*	......	*	*			
—— Dutempleanus?, *D' Orb.*	......	......	*			
Lima globosa, *Sow.*	......	*	......	*	......	*
—— elongata, *Sow.*	*	*	*			
——, sp. nov.						
Avicula gryphæoides, *Sow.*	......	*	*	......	......	*
Perna lanceolata, *Geinitz*	*					
—— Rauliniana, *D' Orb.*	*	*	*			
—— subspathulata, *Reuss.*	*					
—— semielliptica, *Seeley.*						
—— oblonga, *Seeley.*						
Gervillia solenoides, *Defr.*	*					
Inoceramus sulcatus, *Park.*	......	*	*			
—— concentricus, *Park.*	*	*	*	*	*	
Arca nana, *D' Orb.*	*	*				
—— Hugardiana, *D' Orb.*	*	*	*			
Nucula bivirgata, *Sow.*	*	*				
—— ovata, *Mant.*	*	*	*			
—— albensis, *D' Orb.*	*					
—— subelliptica, *Seeley.*						
—— rhomboidea, *Seeley.*						
—— Vibrayeana, *D' Orb.*	*	......	*			
Leda solea, *D' Orb.*	*					
Cucullæa glabra, *Park.*	*	......	*	*		
—— Agassizii, *Pict. & Roux*	......	......	*			
Lucina tenera, *Sow.*	*					
Fimbria gaultina, *Pict.*	......	......	*			
Cardita tenuicosta, *Sow.*	*	*	*			
Tellina phaseolina, *Pt. & Camp.*	*	......	*			
Pholadomya decussata, var. triangularis, *Seeley*	......	*				
BRACHIOPODA.						
Terebratula biplicata, *Sow.*	*	*	*	*	*	*
—— ——, var. Dutempleana	*	*	*			
—— ——, var. obtusa	*	......	*			
Kingena lima, *Defr.*	......	*	*	......	*	*
Rhynchonella sulcata, *Park.*	......	......	*			
—— compressa, *Lam.*	......	......	......	*	*	
—— latissima, *Sow.*	......	......	*	......	*	
CRUSTACEA.						
Palæocorystes Stokesii, *Mant.*	*	*				
Eucorystes Carteri, *M'Coy.*						
Necrocarcinus Beechii, *Deslong.*	*	*				
—— Woodwardi, *Bell*	*	......	......	......	*	*
—— tricarinatus, *Bell*	*	......	......	......	*	
Homolopsis Edwardsii, *Bell*	*					
Hemioon Cuningtoni, *Bell*	......	......	......	......	*	

List of Fossils (continued).

Gault Fauna.	Lower Gault.	Upper Gault.	Vraconnien (Cheville &c.).	Upper Greensand.	Warminster beds.	Chalk-marl and Grey Chalk.
Cyphonotus incertus, *Bell*	......	......	......	......	*	
Diaulax Carteriana, *Bell*	......	*				
Xanthosia granulosa, *M'Coy.*						
Etyus Martini, *Mant.*	*	*				
—— similis, *Bell.*						
Hoploparia sulcirostris, *Bell*	*	*				
—— scabra, *Bell*	*					
Phlyctisoma tuberculatum, *Bell.*						
—— granulatum, *Bell.*						
Glyphæa cretacea, *M'Coy*	......	*?	......	......	......	*
—— Carteri, *Bell.*						
Scillaridea cretacea, *Seeley, MS.*						
Squilla M'Coyi, *Seeley, MS.*						
Scalpellum arcuatum, *Darw.*	......	*	......	......	......	*
—— unguis, *Sow.*	*	*				
—— læve, *Sow.*	*	*				
? —— glabrum, *Roem.*	......	......	......	......	*	*
Annelida.						
Serpula articulata, *Sow.*	......	*				
—— plexus, *Sow.*	......	*	......	......	*	
Echinodermata.						
Cidaris gaultina, *Forbes*	......	*				
Pseudodiadema scriptum, *Seeley.*						
—— inversum, *Seeley.*						
—— Barretti, *Woodw.*						
—— Carteri, *Woodw.*						
—— intertuberculatum, *Seeley.*						
—— fungoideum, *Seeley.*						
Hemiaster asterias ?, *Forbes*	*	*				
——, sp.						
—— M'Coyi, *Seeley*	......	*				
Holaster lævis ?	......	......	*	*	*	
Salenia, sp.						
Galerites, sp.						
Pentacrinus Fittoni ?, *Aust.*	*	*				
Actinozoa.						
Trochocyathus conulus, *Edw.*	*	*	*			
—— angulatus, *Dunc.*	*	*				
—— Harveyanus, *Edw.*	*					
Sarcinula favosa, *Mich.*						
Spongida.						
Ventriculites cavatus, *T. Smith.*						
—— mammillaris, *T. Sm.*						
—— texturatus, *T. Sm.*						
—— quincuncialis, *T. Sm.*	......	*				

List of Fossils (continued).

Gault Fauna.	Lower Gault.	Upper Gault.	Vraconnien (Cheville &c.).	Upper Greensand.	Warminster beds.	Chalk-marl and Grey Chalk.
Cephalites compressus, *T. Sm.*						
—— guttatus, *T. Sm.*	......	*?				
—— capitatus, *T. Sm.*						
Brachiolites tubulatus, *T. Sm.*						
Chenendopora, sp.						
Polyacantha Etheridgii, *Sollas.*						
Rhabdospongia communis, *Soll.*	*					
Bonneyia bacilliformis, *Soll.*	*	*				
—— cylindrica, *Soll.*						
—— Jessonii, *Soll.*						
—— scrobiculata, *Soll.*						
—— verrongiformis, *Soll.*						
Acanthophora Hartogii, *Soll.*						
Retia simplex, *Soll.*	......	*				
—— costata, *Soll.*						
Hylospongia patera, *Soll.*						
—— calyx, *Soll.*						
—— Brunii, *Soll.*	*	*?				

Part II.—Fauna belonging to the Bed itself.

Chalk-marl Fauna.	Lower Gault.	Upper Gault.	Vraconnien (Cheville &c.).	Upper Greensand.	Warminster beds.	Chalk-marl and Grey Chalk.
REPTILIA.						
Ichthyosaurus campylodon, *Carter*	*	*	......	......	......	*
Plesiosaurus Bernardi, *Owen.*						
—— pachyomus, *Owen.*						
—— cycnodeirus, *Seeley.*						
—— microdeirus, *Seeley.*						
Polyptychodon interruptus, *Owen*	......	*	......	......	.....	*?
Stereosaurus platyomus, *Seeley.*						
—— stenomus, *Seeley.*						
Acanthopholis platypus, *Seeley*	......	......	......	......	...	Genus.
—— stereocercus, *Seeley*	......	......	......	......	...	
Macrurosaurus semnus, *Seeley.*						
Rhinochelys pulchriceps, *Seeley*	......	......	......	......	...	Fragments of Chelonians sometimes found.
—— stenicephalus, *Seeley*	......	......	......	......	...	
Emys sphenognathus, *Seeley*	......	......	......	......	...	
Testudo cantabrigiensis, *Seeley*	......	......	......	......	...	
Ornithocheirus Fittoni, *Owen.*						
—— Cuvieri, *Bowerb.*						
—— macrorhinus, *Seeley.*						
—— platystomus, *Seeley.*						
—— Carteri, *Seeley*	......	......	......	*		

List of Fossils (continued).

Chalk-marl Fauna.	Lower Gault.	Upper Gault.	Vraconnien (Cheville &c.).	Upper Greensand.	Warminster beds.	Chalk-marl and Grey Chalk.
PISCES.						
Otodus appendiculatus, *Ag.*	*	*	*		*	*
Saurocephalus lanciformis, *Harlan*		*		*		*
Notidanus microdon, *Ag.*						*
Acrodus transversus ?, *Ag.*						
—— Illingsworthii, *Ag.*						*
Enchodus halocyon, *Ag.*						*
Edaphodon Sedgwickii, *Ag.*	*	*				*
CEPHALOPODA.						
Belemnites ultimus, *D' Orb.*		*	*	*	*	*
—— plena, *Blainv.*						*
GASTEROPODA.						
Funis elongatus, *Seeley.*						
—— brevis, *Seeley.*						
LAMELLIBRANCHIATA.						
Ostrea frons, *Park.*		*	*		*	*
—— vesicularis, *Sow.*		*	*	*	*	*
—— cunabula, *Seeley.*						
—— lagena, *Seeley.*						
Exogyra haliotoidea, *Sow.*		*		*	*	*
—— conica, *Sow.*, var.		*	*	*	*	
—— laciniata, *Nilss.*				*		*?
Anomia transversa, *Seeley.*						
Spondylus truncatus ?, *D' Orb.*				*	*	*
Plicatula inflata, *Sow.*			*	*	*	*
—— minuta, *Seeley.*						
—— sigillina, *Woodw.*		*				*
Lima globosa, *Sow.*		*		*		*
—— aspera, *Mant.*						*
—— cenomanensis ?, *D' Orb.*						*
Avicula gryphæoides, *Sow.*		*	*	*		*
Radiolites Moretoni, *Mant.*						*
Teredo amphisbæna, *Goldf.*						*
BRACHIOPODA.						
Terebratula biplicata, *Sow.*		*	*	*	*	*
—— sulcifera, *Morris*						*
Terebratulina striata, *Wahl.*					*	*
—— gracilis, *Schloth.*					*?	*
Rhynchonella lineolata, *Phil.*						*
—— Mantelliana, *Sow.*						*
Kingena lima, *Defr.*		*	*		*	*
Argiope decemcostata = megatrema, *Sow.*					*	
ECHINODERMATA.						
Cidaris gradata, *Seeley.*						
—— Sedgwicki, *Seeley.*						
—— Dixoni, *Cotteau*						*

List of Fossils (continued).

Chalk-marl Fauna.	Lower Gault.	Upper Gault.	Vraconnien (Cheville &c.).	Upper Greensand.	Warminster beds.	Chalk-marl and Grey Chalk.
Cidaris Faujasii, *Desor.*						
—— clavigera, *König*	......	......	......	......	......	*?
—— Bowerbankii, *Forbes.*						
Salenia Woodwardi, *Seeley.*						
Discoidea minima, *Desor*	.....	......	......	......	*	*
Echinocyphus impressus, *Seeley.*						
Goniophorus lunatus, *Ag.*, var.						
ANNULATA.						
Palæga Carteri, *Seeley*	......	......	......	......	......	*
Vermicularia umbonata ?, *Sow.*	......	......	......	*	*	*
ACTINOZOA.						
Micrabacia coronula, *Goldf.*	......	......	......	......	*	*
Onchotrochus Carteri, *Dunc.*						
SPONGIDA.						
Chenendopora, sp.						
Brachiolites digitatus, *T. Smith*	......	......	......	*	......	*

EXPLANATION OF PLATES.

PLATE XIV.

Figs. 1, 2. *Scaphites Meriani*, Pict. & Camp.: fig. 1 is intermediate between *Sc. Meriani* and *Sc. Hugardianus*, D'Orb. From the Woodwardian Museum*.

3. *Scaphites Meriani*, var. *simplex*, nobis.

4, 5. *Fusus Smithii*, Sow. Phosphate casts.

6. —— ——. Specimen from the Gault of Folkestone, retaining the shell, in the Museum of the Geological Society.

7–9. *Trochus Tollotianus*, Pict. & Roux. Phosphate casts.

10, 11. *Littorina* (?) *crebricostata*, Seeley. Casts.

12, 13. *Crepidula gaultina*, Buv.: 13 *a* is the profile of fig. 12; 13 *b* is a more elevated form in the possession of Mr. F. A. Buxton, B.A., Trinity College.

14. *Trochocyathus conulus*, Edw. & Haime, showing epitheca and base of attachment.

15. —— ——, showing costated wall; in the possession of Mr. C. T. Clough, B.A., St. John's College.

16. —— ——. Section showing columella and synapticulæ; from my own collection.

PLATE XV.

Figs. 1, 2. *Isoarca Agassizii*, Pict. & Roux. Cast of full-grown individual.

3. —— ——. Cast of young form.

4, 5. *Nucula bivirgata*, Sow. Phosphate casts from Cambridge.

6. —— ——. Unique specimen in the Woodwardian Museum, exhibiting the shell in a phosphatic condition.

7, 8. —— ——. Shell and phosphate cast from the Gault of Folkestone; in my own collection.

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* All the following fossils are in the Woodwardian Museum, except where it is otherwise stated. My thanks are due to Prof. Hughes for kindly allowing me to have them figured.

Fig. 9. *Corbis gaultina*, Pict. Phosphate cast.
10, 12. *Lucina tenera*, Sow. Cast from the Cambridge phosphate-bed.
11. —— ——. Specimen from Gault of Folkestone, with shell, for comparison.
13. *Cidaris gaultina*, Forbes. A fine cast in phosphate, retaining portions of the test. (Two thirds nat. size.)
14. —— ——. Segment of test, from which only one plate is missing: from the Gault of Folkestone, in the collection of Mr. F. G. H. Price, F.G.S.
15, 16. *Pseudodiadema Carteri*, Woodw. Fig. 16 shows segment of same enlarged.
17. —— ——. One of the original specimens in Mr. J. Carter's collection.

Discussion.

Mr. Charlesworth considered that the vexed question of the true relations of the so-called Upper Greensand of Cambridge had been now determined, and that it must be regarded as Gault. The presence of *Endogenites erosa* and other Wealden forms in the deposit at Potton in Bedfordshire, would seem to show that it belonged to the Wealden; while the presence of Kimmeridge species might be taken to prove that it was Kimmeridge. With regard to the so-called coprolites, he remarked that it was difficult to assign those of the Red Crag, as well as those of Cambridge, to their true position. He inquired how did the phosphatic nodules originate? Some observers maintain that they are rolled; but in the Crag the shark's teeth have nodules attached to their base, and these could not have been acted upon by erosion. He thought the phosphates were derived either from decomposed marine vegetation or from excrements.

Mr. Price corroborated all Mr. Jukes-Browne had said, and remarked that he observed in the collection of the so-called Upper Greensand fossils in the Woodwardian Museum at Cambridge a large preponderance of forms which he could assign as belonging to the Gault. In that collection he counted as many as 75 species which he recognized as being similar to those found at Folkestone, 63 of which were common to the Upper Gault, and 12 to the Lower Gault. The whole collection at Cambridge shows as much as 30 per cent. of Gault forms. In the Greensand seam which traverses the Upper Gault at Folkestone, nodules and fossils occur which are identical both as regards species and mineral characters with those from the Cambridge area. The beds denuded in that basin represent X. and XI. of the Folkestone Gault, and part of bed IX., as proved by the presence of *Inoceramus sulcatus* at Cambridge.

Prof. Seeley remarked that when he commenced the study of the question discussed in Mr. Jukes-Browne's paper, the fossils of the so-called Cambridge Upper Greensand were very imperfectly known, and the prevalent belief among palæontologists was that the stratum represented the Gault. As the collections at Cambridge were accumulated, and his acquaintance with English sections of similar deposits was enlarged, he had enjoyed opportunities of discussing the question with foreign palæontologists, and now believed that the deposit essentially represented the English Upper Greensand. He had noticed that the surface of the Gault on which the Greensand rests is eroded, the phosphatic nodules being spread uniformly, though the Vertebrate fossils were often contained in hollows of the surface of the Gault. Occasionally the phosphatic bed was covered by a discontinuous dark-coloured clayey bed, divided from the Chalk Marl by a sharp line of bedding. He thought that this band might result from denudation of Gault; and the fact that it did not interfere with the continuity of the bed of phosphatic nodules seemed to show that the denudation was local and of small extent. The fact that sand was superimposed upon clay, necessarily implied an upheaval of the sea-bottom; and therefore the newest-formed beds of the Gault were sure to be denuded to some extent in consequence. But while this circumstance would explain the occurrence of a small percentage of Gault species, it rendered it rather improbable that so varied a fauna should have been derived from a denuded portion of one stratum. Mr. Seeley's own investigations had not led him to detect in the bed any preponderance of Gault forms. He further found that the remains of Vertebrates in the Cambridge Upper Greensand were associated series of bones, which would not be the case were they derived fossils, and that no species of reptile had yet been identified as common to the Cambridge Greensand and the Gault. He thought that the thinness of the Cambridge Greensand, as well as the complex nature of its fauna, was only to be understood by considering the circumstances of physical geography under which the deposit originated; and upon this some light was thrown by the thinness of the Kimmeridge Clay in the same area, and by the occurrence of phosphatic nodules in that area in the so-called Neocomian beds. These beds, like the Cambridge Greensand, contain fossils derived from the Carboniferous Limestone and fragments of Palæozoic rocks; so that the phosphates might have been furnished to the sea in which the deposit was formed by denudation of eruptive dykes of apatite, such as Mr. D. Forbes had informed him were to be met with traversing Palæozoic rocks in Spain, Norway, and other countries. Taking all these facts into consideration, he was inclined to hesitate for the present in accepting Mr. Jukes-Browne's hypothesis.

Mr. Forbes, with reference to Mr. Seeley's observations, stated that he had found true eruptive lodes or dykes of phosphate of lime (phosphorite or apatite) traversing the Silurian and Devonian strata and granites of Estremadura in Spain and Portugal, and often extending for miles, and also others breaking through the metamorphic schists of the south of Norway. Some years back he had explained the phosphorite in the deposits of Nassau as resulting from submarine eruptions, which brought it up and left it on the sea-bottom in the form of breccia and tuff, precisely as a volcanic rock would do under similar circumstances. So far as he had examined the phosphatic nodules of the Cambridge Greensand, however, he had not found that their mineral structure indicated any such eruptive origin.

The Rev. T. G. Bonney remarked that Mr. Seeley's observations bore upon a large question, affecting our whole system of geological nomenclature rather than the immediate subject. The nomenclature being as it was, he thought Mr. Browne was fully justified in his conclusions. In the Cambridge deposit we have:—two distinct faunas—one, as shown by percentages, related to the Chalk-marl, the other to the Upper Gault; two conditions of mineralization; evidence of erosion in the irregular junction of the two beds, in the waterworn condition of many of the nodules, in the fact that they had *Plicatulæ*, Polyzoa, &c. attached; the nodules also could be detected in the Gault, not only in the particular seam which had been described, but at intervals throughout the mass; also erratics of some size occurred in the phosphate bed. These facts, he thought, proved the existence of a break. He thought that associated bones were rarer than Mr. Seeley described them to be. It appeared to him that some of the speakers had forgotten that the question of the origin of the nodules had already been brought before the Society by Mr. Sollas and Mr. Fisher, who had shown very many of them to be phosphatized sponges.

Mr. WHITAKER said that the mapping of the parts of Bedfordshire, Buckinghamshire, and Hertfordshire referred to in the paper, for the Geological Survey, led him to conclude (in 1868) that the nodule-bed is really the base of the Chalk-marl, there being a regular passage upwards into the latter. He remarked on the difficulty there often was of distinguishing between the lower part of the Chalk-marl and the top part of the Gault before the nodule-bed was laid open through the district he referred to.

Mr. HAWKINS JOHNSON said that the microscopical structure of the phosphatic nodules is identical with that of septaria from the London Clay, with that of the Clay-ironstone nodules of Yorkshire, and with that of some septaria from the Kimmeridge Clay, and of the phosphatic nodules from the Crag. Moderately thin sections subjected to the action of dilute acid (even acetic acid), and examined while moist, show a structure like that of sponge.

Mr. EVANS remarked that the difference between Mr. Jukes-Browne and Mr. Seeley appeared to be on a question of fact. He remarked upon the difficulty of distinguishing between the Chalk and the Gault in Bedfordshire &c.

Mr. JUKES-BROWNE, in reply, said that he was only concerned with the question of where the coprolites had come from, and not that of how they originated; he had not therefore touched upon the formation of phosphatic nodules. He thought Mr. Seeley had admitted some of the most important points of his paper, viz. the eroded surface of the Gault, the confluence of the Cambridge nodule-bed with that of the Gault, and the consequent derivation of many of its fossils. He must, however, maintain that there was a complete passage between the Greensand and the Marl above, and no trace of a second line of erosion, as Mr. Seeley appeared to think. With regard to the vertebrate remains, those preserved in dark phosphate were always worn and rolled, while the associated bones Mr. Seeley spoke of were light in colour, and undoubtedly belonged to the formation itself, *i. e.* to the base of the Chalk-marl. Lastly, the lists and percentages contained in the paper would show whether or not there was a preponderance of Gault forms in the deposit; and the author was quite prepared to abide by observed facts and palæontological results.

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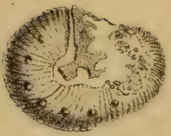

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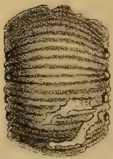

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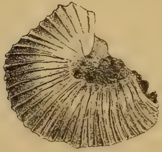

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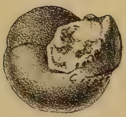

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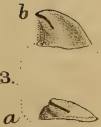

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G. H. Ford.

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CAMBRIDGE FOSSILS.

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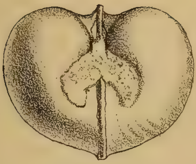

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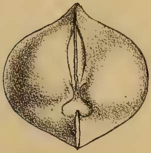

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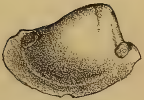

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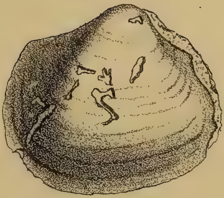

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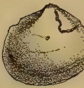

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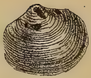

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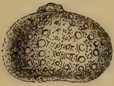

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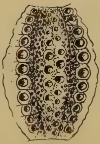

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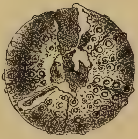

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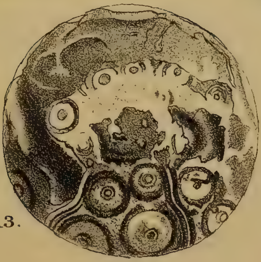

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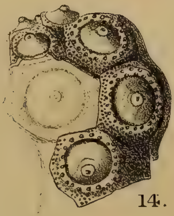

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CAMBRIDGE FOSSILS.

19. REMARKS *on the* WORKING *of the* MOLAR TEETH *of the* DIPROTODONS. By GERARD KREFFT, Esq., F.L.S. &c., Curator and Secretary of the Australian Museum at Sydney, New South Wales. (Read June 24, 1874.)

(Communicated by the President.)

[Abridged.]

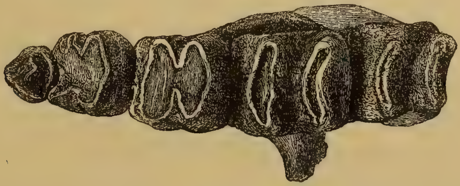
THE 'Descriptive and Illustrated Catalogue of the Fossil Organic Remains of Mammalia and Aves exhibited in the Museum of the Royal College of Surgeons of England' contains, on plate vi., ten figures of the molar teeth of the lower jaw of the extinct gigantic marsupial Pachyderm of Australia (*Diprotodon australis*), natural size.

In a subsequent paper, read before the Royal Society, Professor Owen figures the same teeth again (Phil. Trans. 1872, plate xl. figs. 1, 5, 9, 12, and figs. 2, 6, and 16), leaving out no. 1, no. 1′, and no. 4′ of the Royal College of Surgeons' plate. On plate xxxviii. of the Philosophical Transactions for the year 1872, the same author figures "the outer side view of the right upper molars, *in situ*, of a large, probably male, *Diprotodon*;" also, under no. 1, the grinding surface of the same with part of the bony palate.

Comparing the upper with the lower series, I have come to the conclusion that the latter cannot be correct, because the whole of the teeth, from first to last, show no sign of abrasion, whilst the upper ones do this in a remarkable degree. The fact is, that when the last tooth breaks through the gum the first of the series is already worn flat, and the premolar is often lost soon afterwards. I desire to point this out, and beg to mention here that I have never seen a series of teeth such as Professor Owen has figured, though many abraded examples with the last molar only half through the bone, and yet already worn, have come under my notice.

I send a view of such a gradually worn upper series (fig. 1) which appears to me to be almost identical with that figured by Professor Huxley in the 'Quart. Journ. Geol. Soc.' vol. xviii. pl. xxi. figs. 4 and 5.

Fig. 1.—*Working Surface of the Premolar and four Molars (the perfect set) of* Diprotodon minor. (About one third nat. size.)



In conclusion, I beg to point out the peculiar manner in which the premolar of the Diprotodons has been gradually modified from the typical serrated and broad tooth, as we know it in the Kangaroo tribe, and more particularly in some of the Bettongs, to the rounded premolar of the Phalangers. In the gigantic species, such as the *Diprotodon*, we often find premolars which are evidently nothing more than the elongate typical Bettong tooth doubled up, an excellent example of it being afforded by Professor Huxley's drawing on the plate before referred to, figs. 2 and 3 (Quart. Journ. Geol. Soc. vol. xviii. pl. xxi.).

I take this opportunity to draw the attention of palæontologists to the erroneous conclusions often arrived at by those who are not intimately acquainted with the modern marsupial fauna, and who believe, because in the Kangaroo tribe the female is generally smaller than the male, that the same rule may be applied to the Phalangers, and more particularly to the gigantic extinct Phalangers belonging to the genus *Diprotodon*.

I believe that my view, regarding *Diprotodon* and allied genera being true Phalangers, has been generally accepted; and as in this tribe the female is often larger than the male, it would not be correct to class fossil remains, and more particularly molar teeth, as belonging to female or young animals (of the species *Diprotodon australis* for example) because these teeth happen to be smaller than the teeth which are generally put down by otherwise great authorities as the teeth of *old males*.

Some of the largest Wombats and the largest Koala in the Australian-Museum collection are *females*. The common Phalangers (*P. vulpina*), whereof I once obtained more than fifty specimens for this purpose, proved my surmise to be correct, the largest animals being often females.

20. *The* Rocks *of the* Mining Districts *of* Cornwall, *and their* Relation *to* Metalliferous Deposits. By J. Arthur Phillips, Esq., M.I.C.E., F.G.S., &c. (Read March 10, 1875.)

[Plate XVI.]

The more striking geological features of the mining districts of Cornwall are so generally known as scarcely to require description. The most commonly occurring rock is "killas," or clay-slate, through which four large and several smaller protrusions of granite have taken place*.

The cleavage-planes of the slates almost invariably dip from the intruding masses of granite, but usually at a less angle than the line of contact of the two rocks. Near the point of junction the granite often becomes fine-grained, and not unfrequently sends off veins into the adjoining slates. Masses of granite are also sometimes found imbedded in slate; and fragments of slate enclosed in granite are occasionally met with. At Herland, in the Crowan district, at a considerable distance from any known body of granite, isolated masses of this rock have been found at a depth of 110 fathoms†; and somewhat similar disconnected granitic blocks are said to occur, 49 fathoms deep, at Huel Buller, near Redruth‡.

The granite constituting the larger areas is usually divided into floors resembling beds, which form sheets in the central portions of the several masses, while the edges bend beneath the surrounding sedimentary rocks, and approximate in conformation to the surface of junction between the two. The granites of Cornwall and of Dartmoor probably belong to the same geological age; and there is evidence that the great upheaval of the granite of the latter locality occurred in Post-Carboniferous times.

The slates in the vicinity of granite are usually of a green, brown, purple, or violet hue; but those which are situated at a distance from it are often grey, bluish grey, deep blue, brownish yellow, or buff§. In the western portions of the principal mining district the slates are believed to be non-fossiliferous; but in the eastern part of the county various organisms occur, both in the killas and in its associated beds of limestone, which indicate that these rocks belong either to the Devonian or to the Lower Carboniferous period. It is, however, probable that some of the rocks of south-western Cornwall may be of Silurian age.

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* The granite of the Germoe district, including the Godolphin and Tregoning Hills, is here classed with the smaller masses.

† W. J. Henwood, F.R.S., Trans. Royal Geological Society of Cornwall, vol. v. p. 36.

‡ *Ibid.* p. 157.—The fragments of granite enclosed in slate may have become detached from intrusive masses, and have subsequently been displaced by faults.

§ W. J. Henwood, Journal of the Royal Inst. of Cornwall, vol. iv. (1873–1874) p. 10.

"Elvan-courses," or dykes of granite or of quartz-porphyry, not only traverse the granites and slates, but also pass indiscriminately through all the other rocks of the mining districts. Their direction is most commonly to the north of east and south of west; but there are numerous exceptions to this rule. In width they vary from a few feet to many fathoms. As these dykes intersect the granite, which itself sends off veins into the killas, it is evident that their protrusion must have taken place subsequently to the consolidation of the former rock.

In addition to the protrusion of granite in Post-Carboniferous times, and the subsequent ejection of elvans, evidences abound of active volcanic action, and of the outpouring of enormous volumes of igneous matter during the deposition of the Devonian rocks. These had experienced a large amount of upheaval and disruption prior to the deposition of the Carboniferous series. Many of these rocks are doleritic lavas, and do not materially differ from those which have issued during Tertiary times from the craters of more modern volcanoes*.

Intrusive dykes of diorite &c. are met with in various parts of the county; but many of the "greenstones" marked on the Ordnance Geological Map are unquestionably metamorphosed slates. A considerable area of serpentine and diallage rock occurs in the Lizard district; and serpentine and diallage are also found in the neighbourhood of St. Keverne.

Both the sedimentary and igneous rocks of Cornwall are traversed by innumerable mineral veins, which, although principally composed of siliceous materials, contain ores of tin, copper, lead, and various other metals. Veins yielding ores of tin and copper have usually a direction approximating to east and west, and are seldom found at any considerable distance from the junction of the granite and killas, particularly if elvan-courses do not occur in the neighbourhood. These veins, which are called "lodes," are intersected, nearly at right angles, by others known as "cross veins," which sometimes yield lead or iron ores, but are otherwise, excepting in the immediate vicinity of lodes, usually unproductive.

Veins having a somewhat similar direction to that of true lodes, but which intersect them at a more or less acute angle, are called "caunter-lodes," and are not unfrequently metalliferous.

Killas.

The clay-slate resting upon the flanks of the several granite-masses of Cornwall, and partially filling up the hollows between

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* There is in fact so intimate a mixture of compact and trappean rocks with the argillaceous slates, that the whole may be regarded as one system, the two kinds of trappean rock having probably been erupted, one in the state of igneous fusion and the other in that of ash, during the time that the mud now forming slates was deposited, the mixtures being irregular, from the irregular action of the respective causes which produced them; so that though the one may have been derived from igneous action, and the other from the ordinary abrasion of pre-existing solid rocks, they were geologically contemporaneous. (De la Beche, 'Report on the Geology of Cornwall, Devon, and West Somerset,' p. 57.)

them, varies considerably in colour, structure, and composition, and has in some places been subjected to such an amount of metamorphism as to render it essentially a crystalline rock. Its colour is most frequently grey, greyish blue, or blue; but it has sometimes a green, brown, purple, or violet tint. It is usually lamellar and fissile, but it is occasionally intersected by numerous minute veins of white quartz, by which its cleavage is impaired.

Intercalated bodies of hornblendic slates occur in masses, which are sometimes of considerable extent, as at Penzance and in the neighbourhood of St. Ives.

There can be no doubt that the slates were once deposits of clayey mud, intermixed with variable proportions of siliceous and other sands, resulting from the disintegration and partial decomposition of previously existing rocks. Their chemical composition and mineralogical constitution will consequently vary in accordance with the character of the original rock, the nature and extent of the decomposition they have experienced, and the amount of metamorphism to which they have been subjected subsequently to their deposit.

It has been shown by Daubrée and others that felspathic rocks subjected to prolonged trituration in presence of pure water undergo a decomposition by which alkaline silicates are obtained in solution, while the rock is reduced to the state of mud or sand*. Decompositions of this nature must have been effected on an extensive scale during the transformation of such rocks into clay-slates; and the composition of the resulting sedimentary beds may therefore be expected to differ considerably from that of the rocks from which they were originally derived.

With the view of determining the composition of these slates, and of ascertaining the nature of the changes produced in them by metamorphism, I have, at various times, subjected a great many different varieties to analysis, and have cut and examined, under the microscope, a much larger number of sections. Two concurrent analyses were made of each rock; and the mean results are embodied in the following Table † (p. 322).

I. *Killas from Polgooth Mine, St. Austell, Adit level.*—Has a decidedly argillaceous smell, and adheres slightly when applied to the tongue. Colour generally light grey, marked with darker shades of the same tint, and occasionally stained with yellow or brown. Thin sections of this slate, when examined under the microscope, are observed to be traversed by numerous fissures, which

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* "Le feldspath en fragments soumis à une longue trituration en présence de l'eau distillée, et dans des cylindres en grès, subit une décomposition notable accusée par la présence dans l'eau de silicate de potasse qui la rend alcaline" (Rapport sur les Progrès de la Géologie Expérimentale en France, p. 49). Similar results were obtained by Kenngott, "Ueber die alkalische Reaction einiger Minerale," in the 'Neues Jahrbuch' for 1867, pp. 302, 429, 769.

† In preparing rock-specimens for analysis, several unweathered fragments from each locality were first crushed on a steel anvil; the resulting coarse powder was subsequently well mixed, and a sufficient quantity for all the various estimations was afterwards pulverized in an agate mortar.

Table showing the Chemical Composition of Ten Varieties of Cornish Killas *.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Water { hygrometric	1·00	·66	2·00	·93	·35	·48	·35	·39	4·12	·94
Water { combined	3·09	2·97	1·26	5·65	5·81	·67	4·26	2·74	6·97	2·18
Silica	60·42	63·10	50·92	49·27	53·30	67·32	58·30	40·22	32·98	67·82
Phosphoric anhydride	—	trace	—	—	trace	—	trace	·66	trace	—
Titanic ,,	·21	trace	trace	trace	trace	·13	·23	·15	trace	—
Alumina	20·84	20·15	20·79	18·00	21·73	20·85	21·89	24·01	16·73	9·56
Ferrous oxide	1·89	2·97	4·92	8·55	4·28	1·66	2·57	11·27	13·71	5·02
Ferric ,,	8·17	3·51	13·41	12·68	6·01	2·83	7·06	4·21	7·03	trace
Ferric persulphide	—	—	—	—	—	—	—	S. trace	S. trace	·68
Manganous oxide	·39	trace	trace	·81	—	—	—	—	—	1·20
Lime	1·71	1·27	1·62	2·13	trace	2·03	·39	4·11	4·90	2·58
Magnesia	trace	trace	—	trace	·75	trace	1·10	6·52	11·52	3·42
Potassa	·77	·95	·93	·56	2·92	·60	2·45	1·67	·72	2·37
Soda	1·55	3·14	4·08	·74	4·20	3·37	1·14	3·57	·63	4·32
	100·04	98·72	99·93	99·32	99·35	99·94	99·74	99·52	99·31	100·09
Specific gravity	2·60	2·74	2·73	2·68	2·52	2·71	2·81	2·95	2·82	2·73

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* Phil. Mag. 1871, vol. xli. pp. 87–107; 1873, vol. xlvi. p. 31.

have become filled by crystallized transparent quartz. The structure of this rock is exceedingly indistinct; but when examined between crossed prisms, the mass breaks up into a sort of shadowy mosaic of variously coloured patches, without definite outline.

II. *Killas from Polgooth Mine, Eighty-fathom level.*—This specimen is harder than that obtained from the adit level, and is of a grey colour, marked by reddish-brown spots. The appearance of sections of this rock, when placed under the microscope, does not differ materially from that of those of the slate nearer the surface.

III. *Killas from Polgooth Mine, One-hundred-fathom level.*—The clay-slate from this depth is rather harder than that found at shallower levels. Sections prepared from specimens from this locality very closely resemble those from the eighty-fathom level.

IV. *Killas from Polmear Mine, St. Austell, forty fathoms below the surface.*—This specimen is much contorted, and is readily divided into curved laminæ with glassy surfaces, on which are numerous wavy lines resembling minute ripple-marks. Its colour is grey, in places slightly tinged with yellow. Sections of this rock, when examined under the microscope, exhibit a cryptocrystalline structure, through which numerous small grains of quartz are disseminated. A greenish tint is imparted by flocculent microliths.

V. *Killas from "Sanctuaries," St. Austell.*—This, in common with many other clay-slates lying above the natural drainage-level of the country, is very light in colour, the prevailing tints being grey and buff; and it bears the appearance of alteration.

VI. *Killas from Dolcoath Mine, Camborne, Two-hundred-and-fifteen-fathom level.*—This rock is exceedingly hard, has an imperfect cleavage, and is of a dark grey colour. Under a low power, it is seen to be an aggregation of quartzose granules, through which patches of a greenish tint are disseminated. When a power magnifying 400 diameters is employed, small grains of magnetite are distinguished, from which, as a centre, indistinct fan-like aggregations, of perhaps some variety of chlorite, diverge in all directions*. It also contains some broken and rounded plates of mica, and a few fragments of a brown semitransparent mineral. The two last are mechanically imbedded in the slate.

VII. *Roofing-slate, Delabole, Camelford.*—This slate is of a grey colour, and cleaves readily into thin laminæ. The surfaces indicating planes of bedding are frequently covered by a thin crystallized film of calcite. Sections of this rock, under a 1-inch objective, do not exhibit any very distinct structure; but they are seen to be dotted

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* It may be objected that rocks affording by analysis "traces" only of magnesia cannot contain an appreciable amount of chlorite; it must, however, be borne in mind that when sections are examined under the microscope the green mineral is seen disseminated in a flocculent form, and only in sufficient quantity to impart a greenish tint to certain patches. It is also necessary not to lose sight of the fact that some chloritic minerals contain but a very small proportion of magnesia, while chloritoid is frequently altogether without it.

with dark spots, which a higher power shows to consist of aggregations, about $\frac{3}{1000}$ of an inch in diameter, of hexagonal plates of micaceous iron. In addition to these, transparent belonites traverse the rock in all directions, but principally in planes parallel with the cleavage. These, as well as the crystals of oxide of iron, are evidently not merely imbedded, but have been formed *in situ**.

VIII. *Killas from Botallack, Penzance; surface near lode.*—This rock, which occurs between the granite and the band of "greenstone" forming some portions of the cliff in that part of Cornwall, is of a dark greenish-grey colour, and is very hard. Its cleavage is to a great extent obliterated; but when broken it nevertheless divides into roughly tabular masses. Under the microscope, sections of this rock are seen to consist of a transparent base, through which hornblende and a flocculent greenish mineral are distributed, and in which are imbedded a few minute belonites. Patches of magnetite and a few small crystals of iron pyrites are disseminated throughout.

IX. *Rock from Botallack, One-hundred-and-thirty-fathom level.*—This specimen, sent under the name of "killas," has lost all traces of cleavage, and breaks with the polished surfaces so generally observed in serpentinous rocks. It has a dark-green colour, and slightly attracts the magnetic needle. It will be remarked that both specimens of the so-called killas from this mine contain a large amount of magnesia, which is almost entirely wanting in the clay-slates from the neighbourhood of St. Austell. Under the microscope, this rock is seen to consist of a transparent base, permeated by minute crystals, apparently of hornblende, whose larger axes cross each other in all directions. In addition to these disseminated hornblendic crystals, there are patches made up of bundles of similar crystals, of which the longer axes are arranged in the same direction. Magnetite is disseminated in granular patches throughout the rock. Sections of several of the neighbouring rocks show that hornblende is sometimes more or less replaced by chlorite, and that the amount of disseminated magnetite is very variable.

X. *Killas from Huel Seton, Camborne, One-hundred-and-sixty-fathom level.*—This is a very hard grey clay-slate, of which the cleavage has, in the majority of cases, been to some extent obliterated by metamorphism. No crystalline structure can be detected by the eye; and the rock, in addition to being traversed by strings of white quartz, encloses minute spots and crystals of iron pyrites. Sections are seen under the microscope to consist of bands of transparent granular quartz, alternating with layers of similar quartz, through which minute hornblendic crystals are disseminated.

It is worthy of notice that while the slates of Botallack are highly magnesian, the sea-water which percolates through them into the

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* Almost all the specimens of Cornish killas which have been examined have been found to contain either magnetite or more or less numerous flakes of specular iron ore.

workings of the mine has lost three fourths of its magnesium*. Similar effects appear to have been produced at Huel Seton, where the amount of magnesia in the rock bounding the great cross course, which is traversed by the modified sea-water constituting the well-known "lithia spring," is twice as large as it is in the normal killas of the locality. The magnesium of the sea-water has, in this case, almost entirely disappeared†. With respect to the "talco-micaceous" and hornblendic slates of the Lizard, De la Beche remarks:—"The hornblende slate seems intimately connected with the talco-micaceous slates above noticed, as may be seen near Poltreath, on the west of the Lizard town. It supports the great mass of Lizard serpentine, with an apparent passage of the one into the other in many places"‡.

Pre-Granitic Eruptive Rocks.

In different parts of Cornwall, and particularly in the more northern portions of the county, trappean rocks occur interstratified with the ordinary killas or clay-slates. They are sometimes hard, crystalline, and vesicular; while at others they have a schistose structure, and are less coherent than the non-foliated varieties. The trap-rocks and ash-beds so graduate into the slates, that the change is almost imperceptible; and they have been apparently erupted, the former in a molten state, and the second in the form of ashes, during the period when the mud now constituting the slates was being deposited.

Rocks of this character are described by De la Beche as forming continuous beds of considerable thickness, particularly in the direction of Davidstow and St. Clether. These, together with other very different rocks, are laid down on the Ordnance Geological Map under the general name of "greenstones."

Near the village of Trelill, in the parish of St. Kew, there is a patch of greenstone, which is somewhat extensively quarried for road-material. It is an exceedingly hard and tough stone, without any trace of lamination, of a dark greyish green colour, spotted with white. The white spots chiefly consist of calcite, which fills vesicles occurring plentifully in the original rock. It likewise contains a small proportion of some zeolitic mineral, with which a few of the smaller cavities have become filled. It is to be remarked also that some of the larger vacuities in this rock have been filled with milky quartz.

A good geological section is not to be obtained in this locality; but the trap is known to occupy an area of some fifteen to twenty acres extent. From the number and arrangement of the numerous vacuities which it originally contained, it is evident that this rock did not become solidified under the influence of any considerable amount of pressure, but that, on the contrary, it constitutes a por-

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* Phil. Mag. 1871, vol. xli. p. 95. Calculated from the proportions of the other constituents.

† Phil. Mag. 1873, vol. xlvi. p. 34.

‡ 'Geology of Cornwall, Devon, and West Somerset,' p. 30.

tion of a *coulée* formed under conditions similar to those affecting the lava-flows from more modern volcanoes.

By weathering, the calcite and other secondary minerals filling the cavities become removed, leaving the rock in the form of a cavernous mass of a rusty brown colour, produced by the peroxidation and hydration of the iron present.

On treating the pulverized rock with cold dilute acetic acid, small quantities of ferrous oxide and alumina are dissolved along with the calcareous or dolomitic filling of the vesicles. If, however, these be regarded as forming part of the original igneous rock, and the combining capacity of carbonic anhydride be satisfied from the dissolved lime and magnesia, the results of an analysis made in duplicate may be expressed as follows (sp. gr.=2·80):—

Proportion of carbonate to rock—

	Mean.
Carbonates	25·73
Rock	74·27
	100·00

The carbonates are composed of

Carbonate of calcium	96·20
„ magnesium	3·80
	100·00

The percentage composition of this rock, deduction made of the carbonates, is as follows:—

	I.	II.
Water* hygrometric	·92	·93
Water* combined	4·38	4·58
Silica	48·66	48·37
Phosphoric anhydride	trace	trace
Alumina	23·27	22·92
Ferrous oxide	13·12	13·03
Ferric „	·77	1·01
Manganous oxide	trace	trace
Magnesia	3·20	3·18
Potassa	·57	·63
Soda	5·17	5·22
	100·06	99·87

When thin sections are examined under the microscope they are seen to consist of a base, principally composed of elongated crystals,

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* Hygroscopic moisture of original rock added to weight of dried residue operated on. In the case of this and of other rocks containing a large quantity of ferrous oxide the combined water was collected in a chloride-of-calcium tube.

having the form of plagioclase, intermixed with a little altered augite and a small quantity of more or less peroxidized and hydrated magnetite, through which are disseminated a few felspathic crystals of larger dimensions. The majority of these crystals are evidently plagioclase; but some of them do not exhibit, with polarized light, the striations characteristic of triclinic felspars. Many of the latter are traversed by numerous fissures, filled with carbonate of calcium &c., and, when decalcified, exhibit the appearance of disjointed irregular fragments. From the small amount of potash in the rock, it is probable that some of these may be plagioclase so altered as not to afford the usual distinctive striæ. Others appear to be unaltered, and are probably orthoclase. Similar crystals of orthoclase occur in the lavas of Ischia and of Vesuvius *. The vacuities, the filling of which consists principally of calcite, are not unfrequently lined with chlorite. This appears to have been formed previously to the introduction of the former mineral; and a flocculent greenish mineral is also sparingly disseminated throughout the crystalline base. This rock cannot, I think, be regarded otherwise than as being an altered doleritic lava.

A portion of the lime and magnesia of the original rock has evidently been converted into carbonates; and the proportion of alumina is somewhat higher than is usual in rocks of this class. This might, however, be anticipated when the large proportion of felspar to augite, and the amount of alteration which the rock has undergone, are considered.

At a distance of about half a mile south of the Trelill quarry is another, now abandoned, but which was, until recently, worked for road-material. This has been opened, through slate, to a thick bed of rock, somewhat similar in appearance to the foregoing; but it has a schistose structure, is softer, and also much less cavernous.

The results of a duplicate analysis of this rock, calculated in the same way as before, may be thus rendered (sp. gr. = 2·78):—

Proportion of carbonates to rock—

Carbonates	12·01
Rock	87·99
	100·00

The carbonates are composed of

Carbonate of calcium	98·36
,, magnesium	1·64
	100·00

The percentage composition of this rock, deduction made of the carbonates, is as follows:—

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* Dana, 'System of Mineralogy,' p. 360.

		I.	II.
Water*	hygrometric	·70	·68
	combined	3·10	2·91
Silica		49·90	49·93
Phosphoric anhydride		trace	trace
Alumina		21·09	21·23
Ferrous oxide		11·93	11·86
Ferric ,,		·72	·88
Manganous oxide		trace	trace
Lime		·68	·75
Magnesia		6·86	6·84
Potassa		·63	·57
Soda		4·34	4·32
		99·95	99·97

An examination under the microscope of thin sections of this deposit shows it to be an ash-bed, composed of fragments of vesicular *lapilli* having a very similar composition to that of the lava from Trelill quarry. In this rock, however, the vesicles, which are smaller but more numerous than in the other, contain a larger proportion of chlorite.

It will be remarked that in chemical composition the two rocks do not materially differ, except that the latter contains a larger amount of magnesia. In both cases, however, there can be no doubt that a portion of the material now filling the vacuities has been derived from a partial decomposition of the original rock.

Other "Greenstones."

In addition to the foregoing, a great many very different rocks receive the name of "greenstones." Of these a large proportion are only more or less altered hornblendic or chloritic slates, while others are of igneous origin. They are, however, so numerous, and so different in character, that a more detailed enumeration of them would not be consistent with the limits of the present paper. I shall now, therefore, describe only two well-known greenstones, leaving to a future period the examination of some other varieties.

Greenstone from Botallack.—This rock extends, in the form of a narrow band, along the sea-cliff from Porthleden Cove to a little north of the Levant Mine. It is sometimes schistose, and at others apparently amorphous; the change from the one condition to the other taking place by imperceptible gradations. Its colour is a dull sage-green; and a recent fracture exhibits some indistinct crystalline facets.

An analysis, in duplicate, of an unweathered specimen of the amorphous variety of this rock afforded the following results (sp. gr.$=$2·96):—

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* Estimated as in preceding analysis.

		I.	II.
Water	hygrometric	·21	·20
	combined	·24	·22
Silica		47·90	48·10
Alumina		19·26	19·37
Ferrous oxide		7·55	7·79
Ferric ,,		1·67	1·42
Manganous oxide		trace	trace
Lime		10·57	10·51
Magnesia		7·97	7·53
Potassa		·49	·42
Soda		4·33	4·07
		100·19	99·66

An examination of thin sections under the microscope shows that this rock is largely composed of hornblende, which occurs in the form of contorted crystalline patches, and as thickly matted acicular crystals. Although consisting, to a great extent, of hornblende, it contains a little chlorite, with some magnetite, while the spaces between the hornblendic patches and crystals are filled by an amorphous transparent colourless base.

This rock appears to be an altered hornblendic slate.

Greenstone from Rose Hill, near Castle Horneck.—This rock is not unlike that from the cliff at Botallack, except that it is somewhat darker in colour, has a decidedly schistose structure, and, when freshly broken, presents more numerous, although smaller, crystalline facets.

An analysis, in duplicate, of an unweathered specimen of this rock yielded the following results (sp. gr.=3·15):—

		I.	II.
Water	hygrometric	1·37	1·37
	combined	1·59	1·53
Silica		35·66	35·50
Alumina		21·13	21·16
Ferrous oxide		10·37	10·27
Ferric ,,		14·56	14·92
Manganous oxide		trace	trace
Lime		9·37	9·13
Magnesia		2·75	2·84
Potassa		·93	·97
Soda		2·10	2·12
		99·83	99·81

A microscopical examination of this rock shows that it largely consists of crystalline hornblende, among which a little flocculent chlorite is sometimes sparingly disseminated. It includes numerous rounded patches of some colourless transparent material, which is traversed in all directions by hornblendic crystals, and which does not afford colours with polarized light. This is probably not an eruptive rock, but a somewhat altered hornblendic slate.

Dykes of diorite occur in the neighbourhood of St. Austell &c.; and numerous traps, the composition of which has not as yet been determined, are found in different parts of the county.

Granite.

The granite of Cornwall is usually coarse-grained, but varies considerably in this respect in different localities. In addition to quartz, felspar, and mica, it almost invariably contains schorl, with sometimes, as accessories, chlorite, apatite, fluor-spar, beryl, cassiterite, garnet, and pinite.

In some districts mica is replaced by a talc-like mineral, and the rock thus apparently passes into protogine. Coarse-grained granites are occasionally traversed by granitic veins of a finer texture.

Mica is sometimes almost entirely replaced by tourmaline, as in some parts of the parish of Luxulyan, and near Roche. At Roche Rock and near St. Mewan Beacon the felspar has disappeared, and the rock consists of a mixture of quartz and schorl only.

Table showing the Composition of three varieties of Cornish Granite.

	I.*	II.	III.
Water { hygrometric	·34	·87	·33
Water { combined †	·89	trace	·89
Silica	74·69	74·54	70·65
Alumina	16·21	14·86	16·16
Ferrous oxide	1·16	·23	·52
Ferric „	trace	2·53	1·53
Manganous oxide	·58	trace	trace
Lime	·28	·29	·55
Magnesia	·48	trace	trace
Potassa	3 64	3·73	8·66
Soda	1·18	3·49	·54
Lithia	·10	trace	—
	99·55	100·54	99·83
Specific gravity	2·64	2·66	2·62

The felspar of Cornish granites, which has often undergone a considerable amount of decomposition, is for the most part orthoclase; but a plagioclastic species, stated by Professor Haughton to be albite,

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* Phil. Mag. 1873, vol. xlvi. p. 30.

† The whole of the water retained by crystalline rocks, after they have ceased to lose weight at 100° C., cannot exist in a state of combination. A portion of it is evidently enclosed in the fluid-cavities, vast numbers of which must escape being crushed during the grinding of the rocks for analysis.

is also frequently present. Two differently-coloured micas are disseminated throughout these rocks in the form of imperfectly crystallized flakes. The first, which is black, or dark brown, may be either muscovite or lepidomelane; the second, which is pearly white or pink, is lepidolite.

The quartz in granite seldom occurs in the form of distinct crystals, but is usually granular, and is more or less irregularly disseminated through the rock. It is generally either transparent and colourless or white; but it has sometimes a bluish or greyish tint. Numerous microscopic cavities, partially filled with liquid, are observable in the quartz of all Cornish granites; some, on the contrary, are apparently full, while others are entirely empty.

The preceding Table (p. 330) gives the composition of three different specimens of unweathered Cornish granite, the figures being in each case the mean of two separate analyses.

I. *From Carn Brea Hill, Redruth.*—This is a somewhat coarse-grained granite in which the proportion of glassy quartz is considerable; it contains two varieties of mica, the one nearly black, and the other white or slightly tinged with pink. A microscopical examination of this rock shows that it contains a large amount of monoclinic felspar, but that plagioclase is also present in considerable quantities. The outlines of the felspathic crystals are not in all cases sharply defined, and they are frequently rendered slightly cloudy by greenish flocculent microliths, which may perhaps be the result of metamorphism. Two varieties of mica are distinctly visible, which, together with a little tourmaline, are enclosed alike in quartz and felspar; a few minute crystals of either apatite or beryl are also present. The quartz, which does not form well-defined crystals, is much fissured, the sides of the cracks being sometimes coloured by hydrated oxide of iron. It contains numerous fluid-cavities enclosing bubbles, which, in some of the smaller ones, are observed to be in continual motion.

II. *From Botallack.*—This is a greyish granite with a moderately fine grain, and appears to consist of a nearly equal mixture of transparent or milky-white felspar and glassy quartz, through which are disseminated a few small flakes of mica, and minute crystals of schorl.

Under the microscope the felspar is seen to be of two kinds; and both it and the quartz are in places stained by ferric oxide. The mica chiefly belongs to some white variety; and the fluid-cavities in the quartz, although less numerous, are larger in size than those in the granite from Botallack.

III. *From Chywoon Morvah.*—This granite is composed of a mixture of brownish red felspar and milky quartz, the first in the form of distinct crystals, and the second in that of disseminated crystalline grains. The amount of mica present is very small; and the mineral is usually much decomposed. The proportion of quartz is apparently slightly less than in the generality of Cornish granites.

Under the microscope the felspar is seen to be monoclinic, and is partially replaced by patches of a greenish dust-like mineral; the quartz is penetrated by acicular crystals of tourmaline, and contains numerous gas- and fluid-cavities. It appears to have a decidedly felspathic base, in which the various crystalline components are porphyritically enclosed; in this respect, therefore, it closely approximates to the quartz-porphyries.

Upon the assumption that at the temperature at which the fluid-cavities in natural crystals were formed they were full of liquid, and that when examined at lower temperatures they will be found to contain cavities produced by a corresponding contraction of the liquid, Mr. H. C. Sorby, F.R.S., has endeavoured in his admirable paper "On the Microscopical Structure of Crystals," &c.*, to calculate, approximately, the conditions, with regard to heat and pressure, under which the rocks containing them were produced.

In order to ascertain the relative size of the cavity and bubble, Mr. Sorby measured, when practicable, long and regular cavities; and he states that this may also be determined, with a sufficient degree of accuracy, from those which are equally deep throughout, and which have a flattened vacuity, so that the proportion between the *areas* is that between the *volumes*. "If, however, neither of these can be found, the best approximation that can be made is to be derived from such cavities as are nearly equiaxed, so that the relative magnitude of the cavity and vacuity equals the cube of the ratio of their diameters." He further remarks that "in determining the relative size of the vacuities in fluid-cavities, of course care must be taken not to make use of such as have caught up bubbles of gas along with the fluid, which is more likely to happen with large than with small." "It is therefore best to select those of moderate size, which have vacuities of very uniform relative magnitude, in parts where vapour- or gas-cavities do not occur and the crystal is very solid."

This, however, is manifestly equivalent to choosing for the purposes of experiment only those cavities in which the ratio of the vacuity is as nearly as possible constant, and which must of necessity yield concordant results. When, therefore, we also consider the difficulty of accurately measuring cavities of which the longer diameter varies from $\frac{1}{500}$ to $\frac{1}{1000}$ of an inch, and further take into account the impossibility of finding cavities of which the depth can be proved to be uniformly equal, it will be admitted that this method, by measurement, is open to grave sources of error.

In order, if possible, to avoid these objections, I have attempted to determine, by direct observation, the temperature at which the bubbles in Cornish granites, elvans, and veinstones, disappear. For this purpose a microscope, supported horizontally, and provided with both coarse and fine adjustments, was employed. A rectangular bath of stout sheet brass was furnished on the side nearest the object-glass with a circle of thin covering-glass, secured in its place by paper washers and a screw ring. On the opposite side, a thicker glass was ground into a groove in the metal, and fastened by a

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* Quart. Journ. Geol. Soc. Nov. 1858, vol. xiv. pp. 453-500.

spring collar. The bath, thus constructed, rested on supports attached to the microscope-stand, and could be heated either by a gas-burner or spirit-lamp. A condenser directed the light from a lamp upon the section, which was fixed against the inside of the thin glass cover.

After placing the section in its proper position the bath was filled with melted paraffin; and as soon as a group of suitable cavities was brought approximately into focus, a thermometer was lowered into the paraffin, and heat gradually applied. The observer now watched the filling of the cavities, while an assistant read off the indications of the thermometer.

Some years since, I made use of this arrangement for determining the temperatures at which the bubbles in various Californian veinstones disappeared, and found that very different degrees of heat were required to effect this result—some disappearing at a temperature as low as 80° C., while others were still distinctly visible at 180° C.*

On applying this method to Cornish rocks the results were less satisfactory, since the temperature required to cause the disappearance of the bubbles is higher than can be obtained with melted paraffin; the vapours which were given off also imparted a considerable degree of cloudiness to the object-glass. It was however found that at a temperature of 185° C. some of the bubbles in the granites, elvans, and veinstones had sensibly decreased in size, while the dimensions of others remained apparently unchanged; this would indicate that the bubbles in the latter case could not have been vacuities.

In addition to the usual fluid-cavities enclosing bubbles, the quartz of granites, quartz-porphyries, and veinstones would appear to contain others entirely filled with liquid. These, of course, have no vacuity, and after having been strongly heated assume the characteristics of ordinary gas- or vapour-cavities. It is to be regretted that it has been found impossible to expel a portion only of this water by heat, thus leaving a vacuity in further confirmation of their character; but in all attempts of this nature I have, as might have been anticipated, invariably failed. With regard to such cavities Zirkel remarks that, "as in artificially formed crystals from solution, so in natural crystals there are liquid-cavities which contain no bubble."

After a series of experiments on this subject I have arrived at the conclusion that any method of determining the relation between the cavity and bubbles by measurement must necessarily be beset with grave difficulties, and that the disappearance of the latter, on the application of heat, must take place at very varying temperatures. Such being the case, any calculations based thereon can be reliable only within certain somewhat wide limits; and if the presence of full fluid-cavities be admitted, for which there is the same evidence as for the occurrence of vapour- and gas-cavities, all such calculations must necessarily be fallacious.

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* Phil. Mag. 1871, vol. xxxvi. p. 333.

Zirkel has apparently satisfied himself on this point, since he observes that the calculation by which the temperature at which a rock was formed is deduced from the proportion of the bubble to the liquid, is so very doubtful as to afford no certain data, although it would be otherwise of great value to geologists. Fluid-cavities are constantly met with in the same crystals, in which bubbles vary greatly in relative size; large cavities occur containing small bubbles by the side of small cavities with large ones, &c.*

Elvans.

The elvans of Cornwall are rocks occurring in veins or dykes, which have almost identically the same ultimate chemical and mineralogical composition as the granites of the district; the aggregation of their constituents, however, is often very different.

In elvans the quartz, instead of forming, as in granite, a kind of crystalline residual base, is usually, together with the felspar, porphyritically enclosed, in the form of crystals, in a felspathic or quartzo-felspathic base; mica, schorl, and chlorite are often present to some extent, while pinite is by no means an unfrequent accessory. Graphite in the form of small nodular masses is sometimes found in Cornish elvans. The quartz-crystals of elvans are often double hexagonal pyramids connected at the bases by a short prism. These, which are either glassy and transparent, white and opaque, or somewhat smoky, have often rounded angles. This removal of the edges is sometimes so complete that the patches of quartz in an elvan present the appearance of mere gum-like blebs†. Some of the phenomena connected with the formation of such crystallized bodies will be noticed when describing the microscopic structure of these rocks.

The felspar in elvans is often in the form of large well-defined crystals, which may be either transparent and colourless, or white, pink, red, or grey; in other varieties the crystals are very minute, and can only be discovered by the aid of a lens. They are readily decomposed by weathering into kaolin; and the cavities resulting from its subsequent removal are in some cases lined with göthite. More frequently they have been re-filled with schorl or chlorite; while in the well-known pseudomorphs of Huel Coates, felspar has been replaced by cassiterite.

Schorl occurs either as isolated crystals or in stellate groups. Mica is often disseminated through the mass; but in some cases, particularly in the coarse-grained elvans, it is found in crystalline aggregations.

Elvan-courses vary in width from a few feet to several fathoms; they are more numerous in the vicinity of granite than elsewhere, and traverse alike both granites and slates. They frequently conform, both in direction and in dip, to one series of joints in the

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* Mikroskopische Beschaffenheit der Mineralien und Gesteine, pp. 45–46.

† The crystals of felspar are sometimes similarly rounded, but less frequently and to a much less extent.

rocks which they traverse; but they seldom penetrate between the cleavage-planes of slates*.

In slate they generally consist of a compact felspathic or quartzo-felspathic base containing crystals of felspar and crystalline or gum-like patches of quartz. When enclosed in granite, a similar base prevails, mica and schorl are frequently present, and porphyritically imbedded crystals are numerous, but the rock is generally finer-grained than when it is in slate. In both rocks, however, it is usually coarser and more porphyritic near the middle of the dyke than towards its sides.

Elvans are traversed in all directions by joints dividing them into irregularly shaped blocks; in some cases these are filled with schorl, while in others the filling material is a ferruginous or felspathic clay.

Throughout the principal mining districts of Cornwall the general bearing of the elvan-courses is a few degrees north of east, and they are therefore approximately parallel with the majority of the most productive tin and copper lodes. In other parts of the county elvans are sometimes found running nearly north and south, thus nearly coinciding in direction with the cross veins occasionally yielding lead and iron ores.

The following Table gives the composition of four different varieties of Cornish elvan; but of these the first three only can be regarded as true elvans. I. is coarse-grained and highly porphyritic; II. is much less coarse in grain; III. has a conchoidal fracture and is almost as compact as chert; IV. contains an unusual amount of brown mica, and in other respect differs materially from ordinary elvans.

Table showing the Composition of Four Varieties of Cornish Elvan.

	I.	II.	III.	IV.
Water hygrometric	·11	·26	·43	·34
combined	·49	2·03	1·27	6·11
Silica	72·51	72·82	71·46	47·35
Alumina	13·31	15·12	15·38	20·60
Ferrous oxide	3·87	trace	2·27	1·60
Ferric ,,	trace	1·75	·30	3·10
Manganous oxide	·62	trace	trace	trace
Lime	·60	·52	·47	4·72
Magnesia oxide	1·52	1·06	·22	6·12
Potassa	6·65	6·25	5 51	6·29
Soda	·43	·51	2·79	3·58
Fluorine	trace	...	...	trace
	100·11	100·32	100·10	99·81
Specific gravity	2·62	2·64	2·65	2·70

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* W. J. Henwood. Address delivered at Meeting of the Royal Institution of Cornwall, May 1870.

On comparing the first three of these analyses with one another and also with those of Cornish granites (p. 330), their closely approximate uniformity of composition will at once become evident.

I. *From Pra Sands, near Sydney Cove.*—This elvan, which is in killas, runs north of east to Tregurtha, where it turns southward, passing through St. Hilary. At Tregurtha it sends off a branch in a south-easterly direction, which enters the sea at Pra Sands, where it is about 12 fathoms in width. Towards the centre of this dyke the rock is highly porphyritic, consisting of a mixture of quartz with white and pink felspar, imbedded in a brownish-red felspathic base; the crystals of felspar are sometimes from two to three inches in length. It also contains mica, a little schorl, and occasional crystals of pinite. Under the microscope it is seen to consist of a felspathic base, through which indistinct scales of a greyish green colour are thickly sprinkled, and enclosing porphyritically imbedded crystals of quartz and orthoclase, with a few flakes of mica and a little schorl, sometimes much altered. The quartz has frequently caught up portions of the felspathic base, giving rise to stone-cavities, similar in general appearance to the glass-cavities described by Mr. S. Allport as occurring in the pitchstones of Arran*. The large crystals of felspar are orthoclase, and sometimes enclose quartz, numerous needles of schorl, and flakes of mica. Under a high power the quartz is seen to enclose hair-like crystals of schorl, some of which are broken, together with gas- and fluid-cavities: some of the latter contain no bubble; while others appear to be more or less coated with clay, as though muddy waters were present at the time of their formation.

II. *From Tregoning Hill, Breage.*—This elvan occurs in the form of an east-and-west dyke in the granite of Tregoning Hill, and is a somewhat fine-grained rock composed of a grey felspathic base, porphyritically enclosing a few small crystals of felspar and grains of quartz, together with numerous six- and twelve-sided prisms of pinite; schorl is also sometimes present in small quantities.

Thin sections of this rock do not exhibit under low powers any characteristics which are not recognized when an ordinary specimen is examined by the aid of a lens; but when a combination magnifying 350 linear is employed, the light nebulous grey base is seen to be cryptocrystalline, and to enclose a few distinct crystals of monoclinic felspar, a very small quantity of quartz with schorl and chlorite†, pinite in greater abundance, and a few flakes of mica.

III. *From Mellanear, near Hayle.*—A very fine-grained elvan, occurring in killas, forming a dyke 40 fathoms in width, bearing north of east. Its general colour is a dull bluish grey; it encloses a few distinct crystals of white felspar, and occasionally small nests

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* Geol. Mag. vol. ix. 1872, p. 536.

† In this and many other varieties of Cornish elvan the greyish green nebulous matter, which has been described as pervading to some extent the base of so many different rocks, is seen to become gradually condensed into vermicular aggregations of what appears to be chlorite.

of flaky graphite. The amount of porphyritically imbedded quartz is exceedingly small.

Under the microscope this rock is seen to consist of an amorphous base enclosing a few flakes of mica, and traversed by numerous although somewhat indistinct crystalline planes; it contains small crystals of orthoclase porphyritically imbedded, and a few very small grains of quartz. Some of the felspar crystals have become partially replaced by the nebulous greyish green mineral before referred to.

IV. *From Trelissick Creek, north of Carrick Roads.*—This elvan belongs to a less numerous class, of which the course approximates more nearly to north and south than to east and west. Elvans coursing in this direction have already been stated to be of less frequent occurrence in the mining districts of Cornwall than in other parts of the county. The composition of this rock, however, is very exceptional, even for one of the class, as they do not generally differ materially in the proportions of their constituents from those found in east-and-west dykes.

The width of this elvan, which penetrates a greyish slate, is about 30 feet; and its colour varies from yellow or buff to a dark chocolate-brown, in accordance with the less or greater degree to which the iron present has become peroxidized. Its general appearance is that of a rock composed of a large quantity of mica, with a little felspar, enclosing occasional crystalline fragments of quartz.

Under the microscope thin sections are seen to consist of a nearly equal mixture of quartz, felspar, and brown mica, enclosed in a felspathic base. The felspar is monoclinic; and the quartz contains a few small gas-cavities; but no well-defined fluid-cavities containing bubbles were observed.

In addition to the four above-described elvans, of each of which an analysis in duplicate was made, thin sections of thirteen others were cut and examined; but they in no case exhibited any peculiarity not observed in either one or another of the foregoing.

The fluid-cavities of the quartz in elvans are exceedingly numerous, and are more frequently crystalline in form than those which are found in granites; as in the case of the latter rock, the fluid-cavities contain vacuities of varying relative dimensions, while some of them are without bubbles and apparently full.

Much information with regard to stone- and glass-cavities, and to the conditions under which they are severally formed, is to be derived from a careful examination of the imperfect quartz crystals enclosed in the more coarse-grained elvans.

Fig. 1 (Pl. XVI.) represents an imperfect crystal of quartz, magnified 15 linear, enclosed in a specimen of elvan from Trerice quarry, Crowan. It will be observed that no fewer than six separate intrusions of felspathic base have taken place into its substance; in one instance the enclosed base has become nearly detached in the form of a pear-shaped bleb, while in another the almost totally separated fragment has assumed a pseudocrystalline form.

In fig. 2, which represents another crystal from the same locality, magnified to a similar extent as the foregoing, several separate intrusions appear to have coalesced, while the openings by which they were admitted have again closed ; in addition to the larger mass this specimen encloses several others, together with numerous gas- and fluid-cavities.

Fig. 3. This specimen is from the same elvan, and is represented as magnified to the same extent as the before-described sections ; it exhibits a considerable number of spherical particles of base upon which the substance of the crystal has subsequently closed. These included globules of base are sometimes hollow, and are then merely gas- or vapour-cavities internally lined with a thin coating of basic material. The nature of these bodies may sometimes be determined by the repeated examination under the microscope of a section during the process of preparation; and should any cavity be present, it will often be observed to be laid open.

In fig. 4, which is a quartz crystal (magnified to the usual extent) from the Trerice elvan, all the detached portions of base have, under the influence of forces causing the crystallization of the quartz, assumed a quasi-crystalline form.

From the nature of these intrusions into the quartz of elvans, or quartz-porphyries, it would appear that the crystals, while in a plastic state, and previously to assuming their final configuration, experienced an irregular contraction, giving rise to channels by which a portion of the still liquid or pasty base was drawn into their substance. In some cases the force of crystallization, subsequently exercised, would seem to have moulded them into crystalline forms, while in others it has apparently not been sufficiently powerful to effect this result.

It has been observed by Mr. Sorby, who accounts for them by supposing a portion of the base to have been "caught up" in the crystal, that "stone-cavities are not well developed except in granites whose structure approximates somewhat to that of elvans "*. A careful examination, however, of the quartz of elvans tends to throw considerable light on the mode of formation both of stone- and glass-cavities. The crystals containing them have, by irregular contraction while in a plastic state, drawn into their substance portions of the surrounding base ; in granites and quartz-porphyries having a stony base the result will evidently be stone-cavities, while in pitchstones and other similar rocks glass-cavities will be produced.

The ultimate chemical and mineralogical composition of granites and elvans being the same, they differ only in the mode of aggregation of their constituents ; and they may therefore be assumed to have been derived from a common source, but to have become consolidated under different conditions.

On referring to the Table, p. 322, showing the composition of various Cornish clay-slates, it becomes evident that neither granites nor elvans could result from the rearrangement, by heat or

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* On the Microscopical Structure of Crystals, &c.

otherwise, of the constituents either of one or of any number of such slates.

In the first place, a great deficiency of silica will be observed; and, secondly, slates contain, almost without exception, a larger amount of soda than of potash, while the granites and elvans are potassic rocks.

Mineral Deposits.

The formation of mineral veins is a difficult and very comprehensive subject, and one of which our knowledge is exceedingly limited. I shall therefore, in the present paper, confine myself first to an enunciation of such facts as establish a general connexion between mineral veins and some of the rocks previously described, and subsequently offer certain suggestions relative to the probable influence of eruptive rocks on the production of metalliferous deposits.

The veins producing ores of tin and copper, which in Cornwall are distinguished by the name of "lodes," have a general direction approaching to east and west, and occur in both granite and killas. They are, however, seldom met with at any considerable distance from the junction of these two rocks, or from the vicinity of elvan-courses, which are themselves most numerous in the neighbourhood of the principal granitic areas. These lodes extend without interruption through every rock of the metalliferous series; but their characteristics are locally influenced by the several formations through which they pass. In killas included fragments of clay-slate prevail, while in granite the veinstone contains pieces of that rock; quartz and capel (a dark siliceous slaty material), however, are abundant constituents of nearly all lodes, whatever may be the nature of the enclosing rock. The elvans traverse the same districts as the metalliferous lodes, and, owing to slight differences of direction or dip, are frequently intersected by them, while the cross veins often cut through both indifferently. It is, however, remarkable that although a very large proportion of the lodes are "heaved" or displaced by cross courses, a small number only of elvans are so affected by them. In two instances only does a lode appear to have been displaced by an elvan*. Both lodes and cross veins dip more frequently towards the granite than in a contrary direction.

The granite of Cornwall is believed to be of Post-Carboniferous age; and it is evident that the elvans which traverse both granite and killas must be posterior to the consolidation of at least the upper portions of the former. When, however, elvan dykes are found in slate only, their age becomes more doubtful, since some may have been formed before, and others after the intrusion of those passing alike through granite and killas. From their uniformity of composition, their close approach to parallelism, and their general relation to the principal granitic centres, it may, however, be assumed that they are approximately of the same geological age, and are the result

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* This apparent displacement of two tin lodes by an elvan-course occurs at Polgooth, near St. Austell, and is described by my grandfather in a letter to Mr. Hawkins, Cornwall Geol. Trans. vol. i. pp. 151, 152.

of one or more efforts of vulcanicity which took place after the consolidation of the more superficial portions of the granite, but by which the still liquid material from below was forced upwards.

The lode-fissures containing ores of tin and copper were evidently formed after the consolidation of the elvans which they intersect; and, finally, cross veins must necessarily be of later date than any lodes through which they pass. It must, however, be borne in mind that the fact of one vein having been apparently displaced by another is by no means a proof that its including fissure is older than that of the vein which appears to have displaced it. The two fissures may have been contemporaneous, and their having been open at the same time may have resulted in a local enrichment of the kind so frequently noticed in such localities. It is even possible that, in some cases, the so-called cross vein may be of anterior date to that which it appears to have displaced.

The veinstones of Cornish lodes are chiefly siliceous, consisting of quartz, capel, chalcedony, &c., together with such silicates as schorl and chlorite, one or other of which forms an essential ingredient of all capels. Fluor-spar, calcite, sulphate of barium, &c. also frequently occur, as well as iron pyrites and various other minerals and ores. In some cases these materials are arranged, in duplicate, in bands parallel with the walls of the vein, and following a regular sequence. At other times the vein-matter is composed of a breccia produced by the cementing together, by some siliceous, calcareous, or metalliferous material, of angular masses of the enclosing rock. These included fragments of "country" are frequently enveloped by successive accretions of crystalline quartz, each distinguished by some peculiarity of either structure or colour.

It is also important to observe that when the included fragments consist of slaty matter, their planes of cleavage usually correspond with those of the enclosing rock, and that, when "horses" or large masses of country are enclosed in a vein, there is generally an exact accordance, with respect to bedding, cleavage, and other characteristics, between it and the immediately adjoining wall-rock.

Druses, or "vughs," of more or less considerable dimensions are met with in some part of almost every lode; and the interiors of these are often lined with elongated crystals of quartz, on the surfaces of which the most delicate isolated crystals of calcite, fluor-spar, or of some metalliferous mineral have subsequently been deposited. Chalcedony sometimes alternates with quartz in the banded or "comby" portions of veins; and capped crystals of the latter mineral are found, of which the several parts, being separated by a thin layer of clay, are readily detached. Stalactitic quartz not unfrequently occurs in Cornish lodes.

These and numerous other facts indicate that the contents of mineral veins have been deposited by aqueous agencies; but at what temperature these, in each case, operated, there is not evidence to show, since the ratio of the vacuity to the liquid in the fluid-cavities of the same veinstone appears, like those in rocks, to be subject to considerable variation. That such deposits have sometimes been formed at moderate temperatures becomes probable from certain phenomena observed at a solfatara, known as the Sulphur Bank, near Borax Lake, California. Here one of the fumaroles, which is alternately filled with water at a temperature considerably below the boiling-point, or serves as a channel for the egress of various gases and vapours, has its sides coated with gelatinous silica, beneath which is a layer of chalcedony resting on crystalline quartz. On drying, the gelatinous deposit assumes the appearance of ordinary chalcedony; and the mixture was found on analysis to contain no less than 7 per cent. of mercury in the form of cinnabar. The quartz-crystals of this deposit are seen under the microscope to contain the usual fluid-cavities, in which the bubbles bear the customary varying proportion to the enclosed liquid. It contains, in addition, numerous gas- and vapour-cavities; and many of the fluid-cavities have the form of well-defined negative crystals.

The fissures enclosing mineral veins have evidently been subjected to a series of repeated widenings, such as would result from any movement of their irregular surfaces, but which may also sometimes be the result of mechanical forces developed by the crystallization of the various included minerals. In many cases the original opening would appear to have been a mere comminuted fracture of the rock in a given general direction, between the several planes of which a deposit of mineral substances has subsequently taken place through chemical agency. The final result, in such cases, will be a brecciated veinstone of the kind so constantly met with in mineral districts.

The examination of a very large number of sections made from Cornish veinstones shows that the quartz, which is usually more or less crystalline, contains numerous gas- and fluid-cavities, and encloses ores of tin, copper, zinc, and other metals. Capels are most frequently composed of a quartzose base, through which crystals of schorl are very thickly disseminated either in the form of spheroidal aggregations radiating from various centres, or as acicular crystals crossing one another in all directions. Sometimes, particularly when they occur in slates, capels are a mixture of quartz and chlorite; in others, both chlorite and tourmaline are present. They also often contain innumerable small fragments of the country rock, and are traversed by narrow strings of quartz into which project hair-like crystals of schorl, which are generally attached to the sides of the enclosing fissure.

In addition to the foregoing, capels frequently enclose crystals and crystalline groups of quartz (traversed by belonites of schorl) which sometimes appear to have been broken, by contraction or otherwise, and afterwards repaired by a growth of schorlaceous matter within the crack.

Fig. 5. Represents a patch of crystalline quartz in a capel from Botallack, magnified 15 diameters, which has the appearance of having been thus broken, and the fissure afterwards filled with tourmaline. From the way in which the needles of schorl penetrate into the substance of the enclosing quartz, it would almost appear

that the crystal of that substance must have become cracked while still in a somewhat plastic condition, and that the schorl was thus enabled to penetrate into its substance. In support of this hypothesis may be adduced the facts stated in connexion with the formation of stone-cavities in the quartz crystals of elvans (p. 337), the apparent crystallization of opaline silica at Borax Lake, California (p. 341), and the occurrence of curved crystals of quartz, described by Breithaupt ('Die Paragenesis der Mineralien,' p. 11) as having been procured from a druse in the Grisons.

Some of the fluid-cavities of veinstones, like those of rocks, contain no visible bubbles; but they frequently enclose acicular crystals of schorl, and cubes which are probably common salt.

General Conclusions.

The various facts which have been described will, I think, warrant the following general conclusions:—

1. The clay-slates of Cornwall vary materially in their composition; but under no circumstance could the mere re-arrangement of the constituents of any one of those examined, or of any number of them, result in the production of granite.

2. Some of the "greenstones" of the Ordnance Geological Map are volcanic rocks contemporaneous with the slates among which they are found, and possessing the chief distinguishing features of modern lavas. Others are hornblendic slates, &c.

3. Granites and elvans, having a similar chemical and mineralogical composition, were probably derived from the same source; but the volume of the bubbles in the fluid-cavities of both, having no constant relation to the liquid, does not afford any reliable data from which to calculate the temperatures at which these rocks were respectively formed.

4. The stone-cavities of elvans, and probably of some other rocks, are sometimes the result of the irregular contraction (previously to the solidification of the base) of imbedded crystals of quartz. In rocks having a glassy base the final result will be glass-cavities.

5. The vein-fissures of the tin- and copper-bearing lodes of Cornwall were generally the result of forces acting subsequently to the solidification of the elvans, but operating in the same general direction as those which caused those rocks to be erupted.

6. The fissures thus produced afterwards became filled with minerals, resulting from deposits, by chemical action, from waters and aqueous vapours circulating through them. From coming into contact with highly heated rocks at great depths, these waters were sometimes at a high temperature; but it is probable that, in many cases, the heat was very moderate, and the action comparatively slow.

7. To what extent these deposits were produced by waters rising from below, and how far they were influenced by lateral percolation cannot be determined. The effects produced on the contents of veins by the nature of the enclosing rock, and the frequent occurrence of

deposits of ore parallel with the line of the dip of the adjoining country, would, however, lead to the conclusion that lateral infiltrations must have materially influenced the results.

8. Contact-deposits and stockwerks have been formed by analogous chemical action, set up, in the first case, in fissures resulting from the junction of dissimilar rocks, and, in the second, in fractures produced during the upheaval of partially consolidated eruptive masses. The alteration experienced by stratified deposits in the vicinity of eruptive rocks is probably often due to somewhat similar percolations.

9. It does not appear improbable that quartz may sometimes retain a certain amount of plasticity after it has assumed a crystalline form, and that it subsequently hardens.

EXPLANATION OF PLATE XVI.

Magnified 15 *diameters.*

Fig. 1. An imperfect crystal of quartz from the elvan of Trerice quarry, Crowan. No fewer than six separate intrusions of felspathic base have taken place into its substance; in one instance the enclosed base has become nearly detached in the form of a pear-shaped bleb, while in another the almost totally separated fragment has assumed a quasi-crystalline form.

2. A crystal, from the same locality, in which several distinct intrusions appear to have coalesced, while the openings by which they were admitted have again closed.

3. Specimen from the same elvan; it contains a considerable number of spherical particles of base, upon which the periphery of the crystal has closed after their admission.

4. Quartz crystal, from the Trerice elvan, in which all the detached portions of base have been compressed into quasi-crystalline forms.

5. A patch of crystalline quartz in capel from Botallack; this presents the appearance of having been broken while still in a somewhat plastic state, and the fissure afterwards filled with schorl, crystals of which have penetrated into the substance of the quartz.

DISCUSSION.

Prof. RAMSAY concurred with the author in his opinion as to the origin of lodes. It has sometimes been maintained that all lodes are of igneous origin, whereas it seemed to him that the materials of all the lodes he knew in various mining districts have been deposited from solution.

Prof. HULL thought that the author was on the right track, as he was employing both microscopical and chemical tests in investigating the characters of the rocks. The mapping of contemporaneous volcanic rocks will be hereafter of the greatest interest. He expressed a hope that the term "greenstone" will soon be extinguished, as it is not a name with a definite meaning.

Mr. F. RUTLEY made some remarks on the various rocks to which the name "elvans" had been applied, granites, felstones, and quartz-porphyries having been indiscriminately termed elvans. The name elvanite, proposed by Jukes, being now accepted by many petrologists as a synonym for quartz-porphyry, he was anxious to know whether it was in this sense that Mr. Phillips employed the term. He felt that the author's statements concerning the microscopic characters of killas were very just, since he had occasionally met with instances in which it was not easy to discriminate microscopically between slaty and felsitic matter; and he commented on the difficulty often experienced in determining some of the green hydrous silicates which occur as alteration-products in eruptive rocks, suggesting that in the present state of microscopic inquiry it might be well to adopt the somewhat vague term "Viridite," which was proposed by Vogelsang as a convenient name by which to designate these undetermined chloritic and serpentinous minerals. He could not agree with Prof. Hull in regarding serpentines as altered diorites, as he had not hitherto met with any instances in which the microscopic character of serpentine would warrant such a conclusion.

Mr. JUDD remarked that, in addition to the negative evidence adduced by the author that by no process of metamorphism could the killas of Cornwall be transformed into the material of which the great bosses of granite and the elvans are composed, we have the positive evidence that not only is the composition of these latter, as shown by the author's analyses, identical, but it is also the same as that of lavas which play a very important part in the structure of the globe—namely, the rhyolites or quartz-trachytes. These lavas, moreover, when crystallized, are found to be made up of precisely the same mineral species as granite—namely, orthoclase, quartz, hornblende, or mica, and some triclinic felspar.

Mr. COLLINS asked where sulphate of baryta occurred as a common constituent of a lode, and where protogine was to be met with.

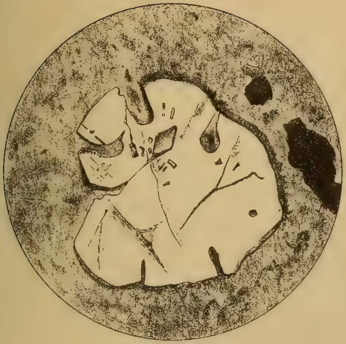
Mr. FORBES did not agree with the author that metallic lodes had been formed by aqueous action, but considered that their metallic contents have in the main come into them from below by sublimation or injection, although afterwards the contents of the veins have been greatly altered by aqueous action, and other minerals thus introduced.

Mr. HULKE inquired why the action of sublimation and aqueous conditions may not have been simultaneous.

Mr. WHITAKER suggested that veins may be formed in different ways. He cited the case of blown sand being cemented by copper, when water from a copper mine percolated through it, and of the cupriferous beds in the New Red at Alderley Edge; and he thought that if water thus dissolves copper, then some veins may have been formed by infiltration from the surface.

Mr. KOCH said that he had been able to compare Saxony with Cornwall, and was much struck by the similarity of the rocks and minerals in the tin-districts of both countries. In fact, after visiting Saxony, he had been able to recognize Greisen and Zwitter-rock in Cornwall associated as in Saxony. He thought steam, charged with fluoric acid, had played a great part in the formation and alteration of dykes and veins. He had found that granite

1.



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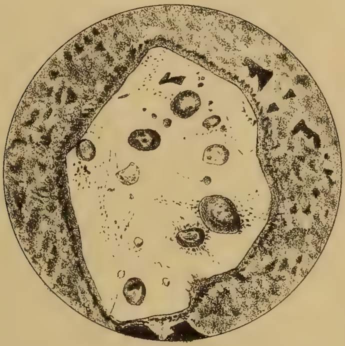

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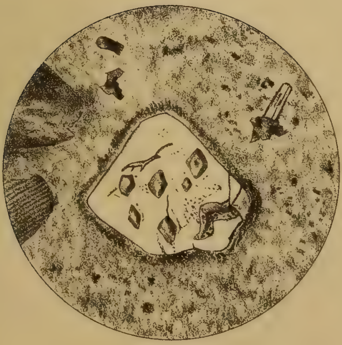

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G.H.Ford.

Mintern Bros. imp.

CORNISH ROCKS.

could be deprived of its mica and felspar by this reagent, and that its quartz crystals became rounded, just as in the elvans. The Cornish elvans and the minerals associated with them, all contained traces of fluorine; he had found that a very small percentage of fluorine could effect great alteration in crystalline rocks, giving rise to a peculiar structure and the formation of a certain class of minerals, *e.g.* tourmaline, fluor-spar, lepidolite, &c., in short the usual minerals accompanying elvans and tin-lodes.

Mr. J. A. Phillips, in reply, stated that some of the minerals were no doubt brought up by superheated steam. He added, that if a vein cuts through stratified rock, the horses always keep in the line of their original stratification, and inquired how this condition of things could be brought about if the deposition of the vein were due solely to the action of heat.

21. *On the* Murchisonite Beds *of the* Estuary *of the* Ex, *and an attempt to classify the Beds of the* Trias *thereby.* By G. Wareing Ormerod, Esq., M.A., F.G.S. (Read February 24, 1875.)

In a paper by myself "On the Waterstone Beds of the Keuper in Somerset and Devon"* a sketch was given of the chief geological features of the coast from Culverhole Point to Littleham Bay, to the west of the Budleigh-Salterton pebble-beds. Since writing that paper I have found pseudomorphous crystals of salt a short distance to the west of Sidmouth, at Windygate, but have not found them to the west of Littleham Bay. The following pages contain an outline of the geology between that Bay and Maidencombe, or Minnicombe, near Torquay.

The chief characteristic features are the beds in which Murchisonite occurs in the higher part, and the conglomerate beds with limestone in the lower part of the series. The last-named beds are specially noticed in Conybeare and Phillips's 'Outlines of the Geology of England and Wales' (page 293). It is there stated that the fragments in the breccia between Dawlish and Teignmouth consist of granitic and porphyritic rocks in many varieties, greywacke, or compact sandstone, and Lydian stone, and calcareous rocks with and without organic remains. These fragments, it is stated, may be regarded as being derived from the adjacent rocks at Babbicombe, Chudleigh, Ashburton, and Dartmoor. In the list of granitic and porphyritic fragments those of felspar are mentioned, and these both in the rocks of which felspar is a component part, and in detached crystals; these for the most part are the opalescent crystals known as Murchisonite. Murchisonite possesses a third cleavage in addition to the two at right angles to each other of orthoclase; and it is upon this third cleavage-plane that the opalescent play of light is observable. Murchisonite, as found at Dawlish, according to the analysis of Mr. R. Phillips, as given in Greg and Lettsom's Mineralogy (page 107) consists of 68·6 silica, 16·6 alumina, and 14·8 potash.

At "Straight point," the headland to the west of Littleham Bay, there is a bed of conglomerate about 8 feet in thickness, composed chiefly of angular fragments of Lydian stone and porphyry, and about 6 feet below that a bed containing white crystals. The cliffs between that point and the target of the Exmouth rifle-range consist of beds of soft red rock, with occasional blue and red clayey beds interstratified, varying greatly in thickness and dipping from about 4° to 5° in the E.N.E. direction. At the point of the high land of Orcombe there is a "throw down" to the east of about 50 feet; near to the Flagstaff point another fault occurs, which appears to run in nearly a northerly direction; and near the rifle-range target another fault occurs running in the same direction. The cliff at this point is of soft red rock with red clay-bands, and also white clay-

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* Quart. Journ. Geol. Soc. 1869, vol. xxv. p. 50.

bands, dipping about 8° E.N.E; these beds are very similar to those seen on entering Exmouth by the Exeter road, and near the Cricket-ground. A little to the west of the target a bed of grey stone crops out which greatly resembles that which has been worked at Clail farm. As that farm lies on the dip and at a higher level than this place, if it is the same bed, which is probably the case, it has been thrown down to the west. From the target to the back of the Life-boat house there is not a good exposure of the strata; but they consist of soft red rock and marly beds. By the footpath leading to the beacon near the Cricket-ground a soft red sandy rock with much false bedding intersected by clay partings and grey beds occurs; these are the same beds that occur by the roadside and at some brick-works on entering Exmouth by the Exeter road, and overlie soft red and grey beds. The strata which have been noticed probably extend inland on the strike to a fault which appears to run in nearly an E.-and-W. direction near Sowden to the south of Lympstone. The beds to the north of this fault will be noticed after the beds by the sea-side have been described.

Below the soft red-and-grey beds a conglomerate bed occurs, which is well exposed at the westerly end of the Beacon; its dip is about 10° E.N.E.; it consists mostly of small angular and subangular fragments of hard brown rock, Lydian stone and porphyry; but I have not found any specimens of granite; and this conglomerate alternates with soft red rock.

Mr. Burridge, a builder at Exmouth, informs me that in sinking for water in this conglomerate he has met with a blue clayey bed. This conglomerate so closely resembles that at Cockwood, on the right bank of the Ex, and also the conglomerate overlying red sand rock where the road from Cofton to Kenton crosses that from Staplake to Mowlish, that, though there is not full evidence to prove the fact, I think there can scarcely be a doubt that the Beacon-beds at Exmouth are the upper portion of those just mentioned; and these I also think form the upper beds of the "Bunter." From Cockwood a nearly uninterrupted section can be traced to near Torquay (fig. 3). Between Cofton Chapel and Cofton Cross a soft red rock crops out from under this conglomerate, and may be identified from Staplake Brook on the north-west to cliffs west of Langstone Point; in this sandy rock near Mowlish detached fragments of Murchisonite appear; and similar crystals are again found in a cutting by the road-side about half a mile to the south-west of Cofton Chapel. At a cutting near Shutton Bridge the sand, which shows much false-bedding, contains small fragments of rocks; but I have not detected any Murchisonite. The small deposit of Murchisonite near Cofton Chapel is nearly on the strike of that at Mowlish, and would properly appear in the cliff near Langstone point. I have not been able to examine those cliffs closely, and the deposit is so trifling that it would be easily overlooked; and I have not recognized it at that point. A fault running in a northerly direction passes to the west of Langstone Point; and I have not been able to decide satisfactorily the exact position of the rocks at Langstone Point in these supposed upper beds of the Bunter. From this fault to Dawlish the soft sandy beds appear in the cliffs; and I have not been able to find a trace of Murchisonite until arriving at the steps leading by the Dawlish Coast-guard Station to the top of the cliff. From this place the Murchisonite can be found as a component part of a soft conglomerate consisting of small angular fragments of various rocks extending on the strike a distance of about two miles and a half by Gatehouse, Gulliford, and Newhouse to near Mamhead, and extending in a westerly direction as a general boundary to a brook called Dawlish Water; the lower part of the bed may be seen by the entrance to Mamhead Parsonage and the cross roads at Whistlade. The only portions of the beds seen are the superficial; and as it has not been quarried, there is no opportunity of comparing it satisfactorily with the beds which it is considered to represent as seen at Exminster and other places. Below this bed soft sandy rock occurs, as seen on the southerly side of Dawlish, in which I have only found a few specimens of Murchisonite; and below this bed lie the conglomerates which have been so ably described by Conybeare and Phillips.

The Murchisonite found in the beds that have been mentioned, generally consists of small detached crystals; in those that will now be described it is found in this state also, but more frequently as a component part of the granitic or porphyritic pebbles. After the second tunnel a series of conglomerate beds commences, differing greatly from those above mentioned, consisting of angular and subangular fragments of hard shale, black siliceous rock, quartz, carbonate of lime, porphyry, granite, limestone, both with and without organic remains, and sometimes in blocks nearly a foot in diameter—and Murchisonite both in the granitic and porphyritic pebbles, and in detached crystals. These are well seen in the bay between the fourth and the Holehead Tunnel, on the southern side of that tunnel at Holehead; and in Smugglers' Lane leading from that point they can be well examined. The conglomerates cease at this place for about three quarters of a mile; and the cliffs between Smugglers' Lane and Teignmouth Tunnel show alternating soft marly and pebbly beds, sometimes containing thin grey bands. Near the Breakwater, at a recess in the cliffs used as garden-ground, a fault can be noticed, the dip on the northern side (about 20° N.N.E) being much greater than that on the southern (10° to 12°); this probably passes in an east-and-west direction to the south of Teignmouth Waterworks, by Onondaga Villa, in Coombe Lane, and to the north of Park Farm, in Bishopsteignton, where the sandstone comes into near contact with the greenstone and is highly crystalline. In the low cliff near the baths at Teignmouth, Murchisonite may occasionally be noticed in the granite pebbles; and in that cliff large rolled stones occur measuring in the face of the cliff 3 feet by 20 inches. When an excavation was made for the foundation of new houses at the corner of Fore Street and Orchard Terrace, in Teignmouth, a deposit of large stones of a similar character was reached. Soft red beds with bands of fragments of various rocks are to be seen in the grounds at Bitton, and at a low cliff to the east of the Tollgate, at Shaldon

Bridge; the dip at that place, as shown by a slaty bed, is 5° N.E. by E. Conglomerate beds with large fragments of limestone then crop out; and these are succeeded by soft beds with pebbles; and where the red sandstone rests on the shaly carbonaceous beds near the ruined summer-house on the left bank of the Teign, it consists of a coarse conglomerate with fragments containing limestone with organic remains and granitic and other rocks. The beds are there intersected by strong lines of parting, ranging from north to south. The Ness point on the south of the Teign has, near the top of the cliff, conglomerate beds of a similar nature to those mentioned as occurring near Shaldon Bridge. Below this beds of soft red rock about 100 feet in thickness occur; and these lie on a coarse conglomerate with large pebbles which forms the base of the cliff at the mouth of the Teign. Several small faults, apparently "downthrows" to the west, occur between this point and Maidencombe or Minnicombe (fig. 3); but the same general character of rock continues—that is, rough conglomerate at the base, overlain by soft rock, and hard conglomerate near the top. The dip is generally in a N.E. direction until near Maidencombe, when it changes to about 4° S.W by S.; the conglomerate beds there rise about 40 feet from sea-level, and are intersected by joints running N. and S. with an inclination of about 30° to the west out of the perpendicular. On the south side of the bay, to the north of Maidencombe, the conglomerates occupy the greater portion of the cliff. From Teignmouth to Maidencombe I have not found detached crystals of Murchisonite: fragments of granite occur in which it exists; and I have found a few spangles in a soft bed at the top of the path leading to the sea at Maidencombe. These rocks may be seen in the cuttings in the lane-sides in the adjoining district; and at a quarry near Higher Gabel a change of dip to the south south-west, similar to that noticed above, may be seen.

The beds that have been mentioned may be classed as follows:—

1. Keuper east of the Ex (fig. 3, *b*).
2. Conglomerate of small angular and subangular fragments of rocks, supposed upper bed of "Bunter" (*c*).
3. Soft red rock, frequently with false-bedding, with a band of Murchisonite (*d*).
4. Conglomerate, chiefly of small fragments and of variable character as to hardness, containing a little Murchisonite but no limestone fragments (*e*).
5. Soft red rock and beds of conglomerate containing numerous fragments of limestone with and without fossils, and Murchisonite mostly in fragments of granitoid rocks, and a little in detached crystals (*f*).
6. Soft sandy and pebbly beds alternating, not containing Murchisonite in appreciable quantity (*g*).
7. Coarse conglomerate, with occasionally large rolled fragments of limestone and granitoid rocks alternating with soft, sandy and clayey beds, not containing Murchisonite in appreciable quantity (*h*).

Keeping these divisions in view, the country north of the fault at Lympstone and of Staplake Brook to Exeter will be shortly described. The beds here found consist of those above the conglomerates with limestone, lying to the west of Dawlish, as they have not been found north of the line just mentioned.

As there are but few exposures on the left side of the Ex, except near that river, the following remarks will be confined to the supposed representatives of No. 3, No. 4, and also, possibly Nos. 5 and 6, the representatives of the beds west of Dawlish. It is but rarely that a good natural section can be observed except in the cliffs; but it is there seen that small dislocations are of constant occurrence; these generally have a N.-and-S. direction. The valleys of the Ex and Clyst probably owe their origin to this cause, and that the softer and more friable beds for the most part occupy that district. In addition to the N.-and-S. faults there appear to be some large dislocations which range from east to west, dividing this country into zones. The most southerly, lying to the south of Lympstone and Staplake, has been noticed. The second zone commences at Lympstone, where a low cliff faces the Ex (fig. 2). This is composed of small angular and subangular fragments of hard brown stone, Lydian stone, porphyry, and granite, with Murchisonite, both in the granite and in detached crystals; and this stratum is overlain by the fine red sandstone, with false bedding, as shown at the north end of the cliff, and in various cuttings. The dip is about 8° N.E. These beds have apparently been thrown down to the west, and appear on the right bank of the Ex, extending on the strike from the south of Powderham Castle to the south of Lower-Marsh Row. The dip of the rocks to the east of Kenn Brook (about 11° N.E.) is so much greater than that on the west of the brook (about 5° N.E.) that very possibly the Kenn flows along a line of fault (fig. 2). From Kenton a thin variable bed of Murchisonite and small angular fragments of rock can be traced to Beavis Bridge on the Kenn; and the soft red rock extends to the south-west, in which I have not found Murchisonite, until it occurs with angular and granitoid fragments on a hill on the Kenton Road, about half a mile to the east of Low Thornton, where it overlies the fine conglomeratic Murchisonite beds, and on the road from Oxton to High Thornton, where iron bands occur in this sand-rock. The exposures are generally so small, and the confusion caused by false-bedding so great, that it is not in my power to state whether this extent of red sand-rock is caused by a succession of faults, or by a widening out of the bed; but it probably arises from the first-mentioned cause.

Below these sandy beds the fine conglomerate with Murchisonite appears (fig. 2, *e*). Some of the beds are soft and friable; but others, which are well exposed at High Thornton, Low Thornton, Bickham, and Trayhill, are of hard rock, much used for building-purposes, and of exactly the same character as those at East-Wonford Quarry and Exminster. A fault can be traced to the east of Low Thornton; the beds on the road to Kenton which overlie this conglomerate are seen low down in the valley to the west of Low Thornton. The rock in the quarry belonging to the Earl of Devon at Low Thornton is fissured by open lines of parting ranging nearly north and south.

The third zone may be regarded as commencing on the hill on the Sidmouth road at Bishops Clyst (fig. 1), where a cutting is carried through soft red sandstone, in which a little Murchisonite in detached crystals is seen, resembling the deposit at Mowlish and Cofton; the dip is E.N.E. at a very small angle. This bed will overlie the soft conglomerate with Murchisonite seen about four miles and a half from Exeter in a roadside cutting near Saint George's Clyst, and a similar conglomerate between the George-and-Dragon Gate and Topsham Bridge over the Clyst. A fault runs along the Clyst river, as on the west bank below Topsham Bridge; and again in a sand-quarry on the road from that bridge to the town the soft red sand-rock with false-bedding reappears and overlies a conglomerate, of the same nature as that described at Lympstone, containing Murchisonite, which appears in a low cliff by the river Ex, dipping 8° N.E., and higher up on the same river at Countess Wear and High Wear. A hard fine conglomerate with Murchisonite and granitoid fragments, which is worked at Exminster quarry (dipping about 5° N.E.), near the South-Devon Railway, on the west of the Ex, is apparently a lower bed of the rock seen at Topsham and Countess Wear. A considerable downthrow to the west exists between this quarry and Exminster village, the overlying red sandy beds being in contact with the basset edges of this rock. This soft sandstone is seen in a cutting by the side of the turnpike road to the north of Exminster, with bands of small fragments of rocks and Murchisonite dipping about 4° N.E. Opposite to the gate of the Asylum it is of a brown colour, and is worked as a sand-pit, and it can be traced on the strike in a southerly direction as far as Lower Marsh Row. There is much false-bedding; and the wells are sunk through it to the fine hard conglomerate beds with Murchisonite; iron bands occur in this sand-rock. The hard fine conglomerate beds with Murchisonite can be traced near their outcrop along the strike from a quarry at Red Hill in the south, by Exminster Asylum (where a well and boring were sunk through it to the depth of 222 feet) to roadside-cuttings to the south of Alphington. From this line the beds extend on the rise about two miles in a south-westerly direction; they are worked in a quarry at the Asylum (dip about 8° N.E.), and other neighbouring quarries, at Kennbury and the quarry near Kennford (where the dip is about 8° N.E.); and thence they continue by Shillingford, where the stone is quarried, to near Little Bowhays. A line from near that place by Spratford Farm to the Exeter-and-Newton road, about four miles and a half from Exeter, may probably be taken as the approximate boundary of the Murchisonite beds; thence to the Greensand and igneous beds on Great Haldon the strata consist for the most part of soft rock, with small fragments of the same description as those in the strata just mentioned, save that I have not been able to detect a fragment of Murchisonite in detached crystals. Occasionally the beds are laminated, as in some peculiar beds near Bond, dipping about 10° N.E.

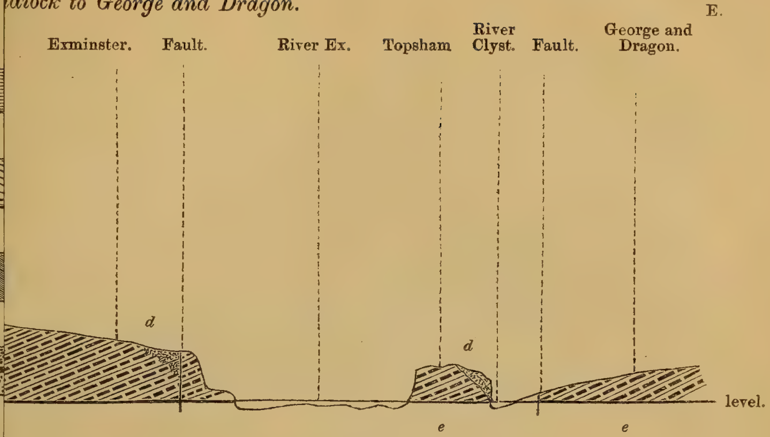
by E., which are very similar to beds which would lie on their strike about a mile and a half distant, at the junction of the road from Shillingford with the Exeter-and-Dunchideock road. A little on the rise, in a cutting by some cottages at Holloway, beds containing large rolled blocks very much resembling those seen near the Teignmouth Baths occur.

I have not been able to trace the Exminster Murchisonite beds on the strike to the north of a line from Alphington to near Little Bowhays; there are not, as far as I am aware, any exposures; but for the following reason I think it probable that they do not appear there on the surface. For the space of about a mile from the hill south of Ide, by the side of the road from Exeter to Dunchideock, soft beds with fragments of rocks closely resembling those just described as cropping out from below the Murchisonite beds occur, dipping in a north-easterly direction; these therefore lie on the strike of the Exminster-district Murchisonite beds. As in the zones that have been described each has been thrown down to the west as regards the next northerly zone, it is not improbable that such has been the case here, and that the fourth zone reaches to the igneous rocks at Pocombe, near Exeter, on its most northerly point, and that the southern boundary passes to the north of Little Bowhays and Alphington and south of Exeter and East Wonford. The fault along the Clyst has been already mentioned. On the eastern side of the Clyst, at Honiton Clyst, as I am informed by Mr. Wyatt Edgell, soft sand with small detached crystals of Murchisonite, like that at Bishop's Clyst, occurs. About two miles and a half from Exeter, on the Sidmouth road, the soft red rock with iron bands is quarried for sand to the depth of 70 feet: the dip is apparently easterly; but the false-bedding is so great that the direction is uncertain. This sand is in close contiguity with, though I have not seen it actually overlying, the beds of small conglomerate containing Murchisonite; these are seen in a back lane leading by the west of the quarry just noticed to East Wonford, near Heavitree. In a lane between the two stone-quarries at East Wonford the soft fine conglomerate beds with Murchisonite are seen overlying a hard rock formed of the same materials dipping about 6° E.; this rock is the same as that worked at Exminster.

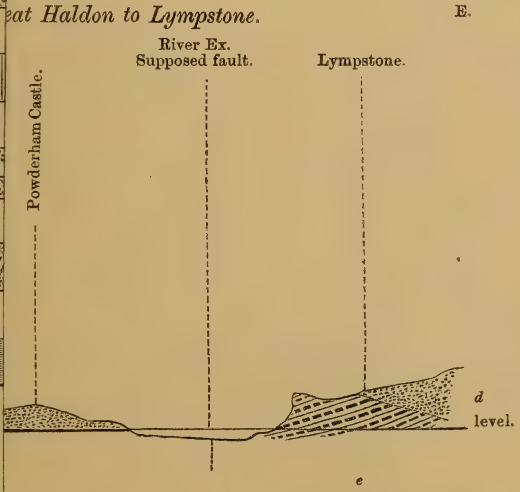
I am only aware of the exposure of the Trias at one place on the west of Haldon; this is at Wapple-well Quarry, near Ugbrook, and by the road leading under the archway to Chudleigh. This is a soft red sandstone, with iron bands and without Murchisonite, and greatly resembles that near Kenton.

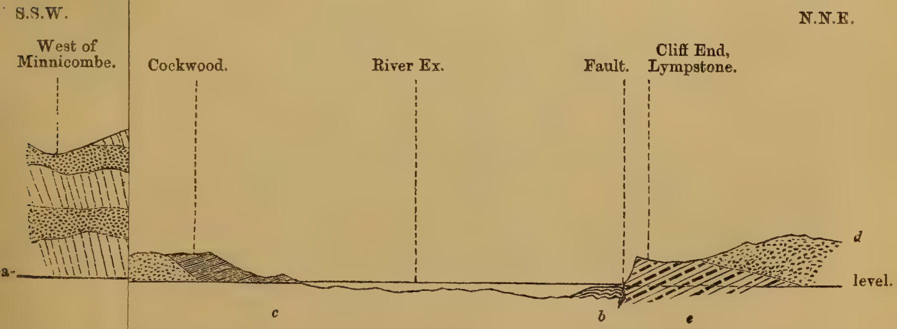
In the district which has been noticed the succession of the various beds is not shown so clearly along the inland zones as in that by the sea-coast; but it is believed that there is sufficient evidence to show that the succession is that of which the short summary was given at the conclusion of the account of the first zone. The beds of the Keuper are only mentioned in the first zone, as they are not seen by the Ex above Lympstone; neither is the conglomerate containing fragments of limestone rocks, as

diock to George and Dragon.



eat Haldon to Lympstone.





[*To face page 352.*

a ▤ Greensand.

b ▤ Keuper (Waterstone).

c ▨ Conglomerate (supposed "Bunter").

d ▨ Soft sandy rock, with thin veins containing Murchisonite.

e ▨ Fine Conglomerate, with much Murchisonite, and no Limestone.

f ▥ Soft rock, with fragments of Limestone, Devonian, and Granitoid rocks and Murchisonite.

g ▤ Alternation of thin sandy and pebbly beds; no Murchisonite.

h ▨ Alternation of thick beds of sand and clay with coarse Conglomerate of Limestone, Devonian, and Granitoid rocks, and Murchisonite in very small quantity.

i ☐ Greenstone.

Horizontal scale 1 inch to 1 mile
Vertical scale 1 inch to 400 feet.

Fig. 1.—*Section from Dunchidiock to George and Dragon.*

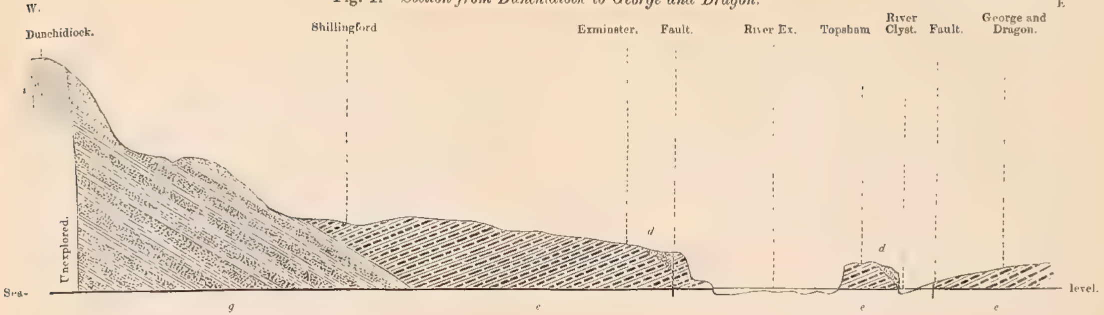


Fig. 2.—*Section from Great Haldon to Lympstone.*

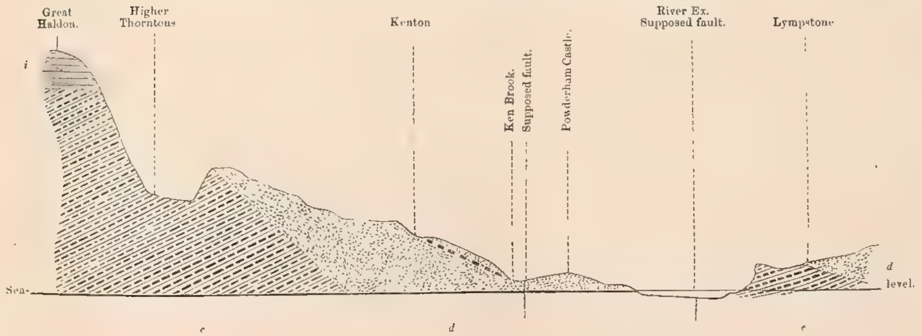
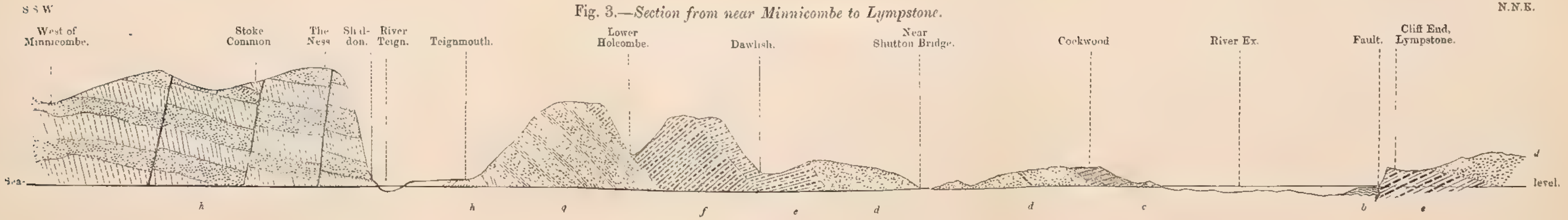


Fig. 3.—*Section from near Minnicombe to Lympstone.*



it does not appear north of the first zone. In the second zone, soft red sandstone, overlying the Murchisonite conglomerate, occurs at Lympstone and in the beds extending from Powderham to Oxton, near which place the Murchisonite beds crop out and continue until they are buried under the Greensand of Great Haldon. In the third zone similar sand-rock, considered from its position to overlie the Murchisonite beds, occurs along the vale of the Clyst, at Topsham, and again at Exminster, from which place the Murchisonite beds extend over a space of more than two miles, when beds without Murchisonite crop out and continue to the igneous rocks near Haldon House, these beds being probably the same as those to the west of Mamhead Parsonage and west of Dawlish. In the fourth zone the soft sandstone is again recognized overlying the Murchisonite beds at East Wonford; a space of three miles then occurs in which I have not been able to see any exposures of rock (though aware that the same conglomerate exists there); and these beds, similar to those cropping out in the third zone from under the fine Murchisonite conglomerate of the Exminster district, appear on the strike of those beds, occupying the district between them and the igneous rocks at Pocombe. In the district which has now been described the sections exposed, with the exception of the cliffs by the sea, are few, and generally consist of roadside-cuttings; so that it is more than probable that many misconceptions have taken place, although care has been taken to guard against them.

A bed of decomposed sandstone is seen overlying the Trias on the road from Teignmouth to Dawlish and along the top of the cliffs between that town and Cockwood; it also occurs near Beavis Bridge, Spratford, Rixtail, and Colemansford near Ideford; and Mr. P. O. Hutchinson, of Sidmouth, informs me that it is found between Otterton and Ladram Bay. As it closely resembles the soft red beds, it is likely to mislead, but may generally be recognized by the presence of flints; whenever any doubt existed, this bed has been regarded as *recomposed*. As the object of this memoir is merely to show the wide extent over which Murchisonite is found, and that this mineral occurs here only in particular beds, which may for that reason be regarded as keys to the geology of the district, minute descriptions of the faults and of the minor changes in the characters of the beds have not been given.

To my friends Mr. A. Wyatt Edgell, of Lympstone, Mr. P. O. Hutchinson, of Sidmouth, Mr. G. Pycroft, of Kenton, and Mr. G. S. Saunders, of Exminster, my thanks are especially due for their great assistance.

Discussion.

Mr. Whitaker stated that the officers of the Geological Survey are engaged in mapping these New-Red beds, but that they have not worked over the district referred to by Mr. Ormerod. He remarked that the divisions of the New Red can be carried into

West Somerset, and that there were signs of faults, just as the cliff-sections show many faults by which the beds are repeated. He understood that the derived Murchisonite does not occur in the lowest bed, in which there is a large quantity of limestone fragments. He inquired whether the Murchisonite came from the granite of Dartmoor.

Mr. Evans remarked that there was much interest in the question whether the materials of the beds described were derived from granites at no great distance. The composition and structure of the crystals should be compared with those of the Dartmoor crystals. The peculiar appearance of iridescence on the cleavage-planes might, he thought, possibly be due to internal decomposition.

Mr. Ormerod, in reply, said that there could be no doubt that the crystals of Murchisonite came from Dartmoor. Some specimens are associated with schorl and tin; and some few specimens of Dartmoor granite contain Murchisonite. He had not experimented on the derived crystals; but certainly some of their changes must be due to their being buried in the Red Sandstone.

22. *On the* PROBABLE EXISTENCE *of a* CONSIDERABLE FAULT *in the* LIAS *near* RUGBY, *and of a* NEW OUTLIER *of the* OOLITE. By J. M. WILSON, Esq., M.A., F.G.S. (Read April 14, 1875.)

IT may be useful in a future geological survey of Warwickshire if I call the attention of this Society to what seems to me the high probability of the existence of a considerable fault in the Lower Lias near Rugby, which has, I believe, hitherto escaped detection. It is accompanied by an outlier of the Oolite, which is not marked in the maps of the Geological Survey.

It will be scarcely worth while to give here the detailed tracing, field by field, of parts of this fault. I propose to print these details in the Report of the Rugby-School Natural-History Society, which will be published in a few weeks. It will be sufficient here to notice its probable existence and position, and to invite to it the attention of some competent geological surveyor.

In the village of Low Morton is a sandpit which is worked against the steep face of a hill to a depth of nearly 50 feet. A few yards from the face of the sand-cliff a well has been sunk 20 or more feet further; and out in the village, and in the bed of the valley, the sand extends to a greater but still unknown depth. No bottom has ever been reached. In a previous communication of mine to the Society will be seen the account of some borings I made for that purpose *. Above the sand-pit is a clay-pit; and there is evidence that the clay is bounded on the side towards the sand by a very highly inclined face of clay, against which the sand is thrown. This face of clay can be traced through the ballast-pit by the side of the London and North-Western Railway, having on one side of it deep sand, and on the other clay reaching to within a few feet of the surface. The whole distance within which it can be minutely traced is more than half a mile.

If this line is continued S.E. it passes close by Kilsby Tunnel, and may be connected with the peculiar difficulties found in the construction of that tunnel from the unexpected inrush of water from large bodies of sand. If continued towards the N.W. it coincides generally with the valley of the Clifton brook; and its existence is again indicated by the great depth of sand in the bed of this valley, which I ascertained by boring, and communicated to the Society. It there passes between Rugby and Brownsover, and is, I suggest, the cause of the existence of the very singular Oolitic deposit on the summit of the Brownsover plateau. There is on this plateau a somewhat extensive Oolitic mass, sometimes rudely stratified, more than 12 feet thick in one place, and quite unmixed with other rock, so as to preclude the idea which I once entertained, on a less complete examination of it, that it was an Oolitic drift. At its edges it is much worn with water, and mixed with materials derived from the Lias;

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* Quart. Journ. Geol. Soc. vol. xxvi. p. 199.

it is found in places scattered over more than a square mile. It has a Stonesfield-slate character.

This line of fault continued further would connect with the Atherstone and Nuneaton fault, and agrees with it in having its downthrow on the N.E. side.

As regards the amount of the throw it is not easy to speak confidently. At Hillmorton, however, it cannot be less than 120 feet; and at Brownsover it may be as much as 500 feet, if I am right in my view of the origin of the Oolitic cap to the Brownsover plateau.

There will be some points of special interest in determining the date of this fault, and its effects on the valley-system in its neighbourhood. It appears to me to have caused the existence of that extinct lake that I spoke of before, and to have altered the watershed. But it has left very few traces on the surface, which is here, for the most part, deeply overlaid with drift.

I may perhaps be permitted to mention that the Natural-History Society of the School has just constructed a model, on the scale of 6 inches to the mile, of our neighbourhood, and that any one who should feel inclined to come down and examine into the question, and thinks that an inspection of the model would assist him, will be made most welcome to all the assistance in our power.

Discussion.

Prof. Ramsay said that he was puzzled with the description of the sands and clays brought together vertically by a fault, and that he had never seen a fault of Postglacial age. He did not think the phenomena described were due to a fault. With regard to the supposed Oolitic outlier, which was said to be of Stonesfield Slate resting upon Lower Lias, he did not see how such an arrangement could be brought about by a fault; for underneath the Stonesfield Slate in that district we naturally expect to find the Inferior Oolite series and the Upper Lias and Marlstone. The Oolitic mass had probably been conveyed to its present position by glacial action, as in many cases in the same parts of the country large masses of rocks occur in remarkable positions, as, for example, an erratic mass of Marlstone overlying Oxford Clay.

Mr. Tate stated, in confirmation of the remarks of Prof. Ramsay, with which he fully agreed, that in Yorkshire he had seen a great mass of Cleveland ironstone resting upon Upper Lias.

23. *The* PHOSPHORITE DEPOSITS *of* NORTH WALES. By D. C. DAVIES, Esq., F.G.S. (Read February 10, 1875.)

IN the year 1863 a working miner picked up a piece of black-looking stuff in a small ravine above Cwmgwynen farm-house, five miles west of the town of Llanfyllin, in North Wales. His discovery excited his curiosity, and led him to make some trial-holes in the ravine, in the hope that he might find the substance in bulk. He was successful in this; but the newly found substance perplexed both himself and his mining friends. It was strange to them all, except that some of them pronounced it manganese, and others rotten sulphur. At last, through the late Mr. Hope Jones, of Hooton, Cheshire, the mineral found its way into the hands of Dr. Voelcker, for analysis. Dr. Voelcker found that the best samples submitted to him yielded over 60 per cent. of phosphate of lime, and the most impure over 40 per cent.

At the meeting of the British Association, in Birmingham, in 1864, Dr. Voelcker called attention to the discovery, and rightly estimated the quantity of phosphate, in the property to which his attention had been directed, at over two million tons. Meanwhile preparations were being made for mining the newly discovered substance, and bringing it into the market. Searches, too, were made for the mineral on adjoining properties, which resulted in its discovery at Penygarnedd, to the N.E., and Pwllywrach, to the S.W. of Cwmgwynen, under similar conditions. The district was one well known to me previously; and I had occasion to visit the new workings repeatedly. In June 1867 I published in the 'Geological Magazine' a short account of the deposit, in which I gave illustrations of the manner in which it occurred, together with its relation to the surrounding strata. Early in the year 1872 I was asked to examine a similar deposit, which had just been discovered in a like manner at Craig Rhiwarth, in the Berwyn Mountains, between Llangynog and Bala, some six or seven miles to the west of Cwmgwynen. I at once, as I had anticipated, recognized in the new discovery the old bed, which, though now widely separated from the one first discovered, had evidently once been continuous with it.

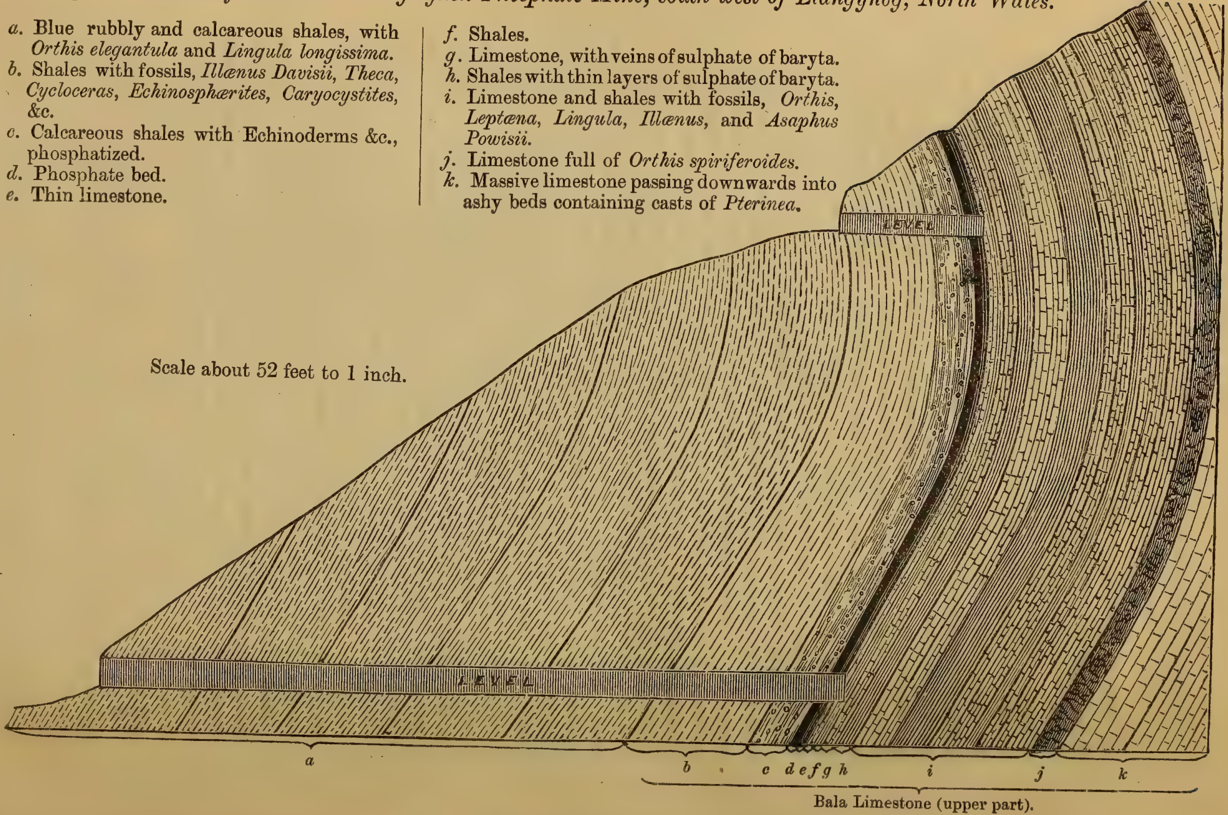
Since then it has fallen to my lot to open up "*a mine*" at the latter place; and, partly as a consequence of my connexion with this mine, I have had occasion to visit several other places in North Wales where the deposit has been found. These are as far apart as the vicinity of the town of Llanfyllin, and the hills ranging west and north of Dinas Mowddwy.

I propose, in this communication, to combine with the remarks made in my paper of 1867 the result of the observations made by me during my closer acquaintance with the deposit during the last few years.

The deposit occurs in a bed whose geological position is at the *top* of the Bala Limestone and immediately under the shale by which

Fig. 1.—*Section of Strata at Cwmgwynen Phosphate Mine, south west of Llangynog, North Wales.*

- *a.* Blue rubbly and calcareous shales, with *Orthis elegantula* and *Lingula longissima.*
- *b.* Shales with fossils, *Illænus Davisii, Theca, Cycloceras, Echinosphærites, Caryocystites,* &c.
- *c.* Calcareous shales with Echinoderms &c., phosphatized.
- *d.* Phosphate bed.
- *e.* Thin limestone.
- *f.* Shales.
- *g.* Limestone, with veins of sulphate of baryta.
- *h.* Shales with thin layers of sulphate of baryta.
- *i.* Limestone and shales with fossils, *Orthis, Leptæna, Lingula, Illænus,* and *Asaphus Powisii.*
- *j.* Limestone full of *Orthis spiriferoides.*
- *k.* Massive limestone passing downwards into ashy beds containing casts of *Pterinea.*



Scale about 52 feet to 1 inch.

that limestone is overlain (see section, fig. 1). The bed varies in thickness from 10 to 15 inches. It is black in colour from the graphite it contains; and its appearance is that of a number of concretions, which range in size from that of an egg to that of a full-sized cocoa-nut, closely packed and even running into each other, and cemented together by a black matrix. The concretions have often a polished appearance, which is also due to the presence of graphite; and frequently along the course of the bed the phosphorite is charged with concretions and crystals of sulphide of iron. Near the outcrop of the bed this becomes oxidized, and the deposit changes its black for a rusty appearance. The concretions, as will be seen by the analyses which accompany this paper, contain the most phosphate of lime, usually 64 per cent.; but the matrix also contains a portion; so that the average yield of the bed is about 46 per cent. Was it from the disintegration of a somewhat similar bed that the rolled and more widely diffused phosphatic nodules of Bedford, Cambridge, and Suffolk were derived?

The bed is underlain by a thin bed of crystalline limestone, which does not usually exceed 6 inches in thickness, though there are a few exceptions to this rule. This also contains phosphate of lime, sometimes to the extent of 15 or 20 per cent. There is but one bed of phosphorite; and it is very persistent in its continuity, and extends over a large area. Indeed there cannot be any doubt that wherever the Bala Limestone is found in North Wales or the borders, this deposit will be found, more or less pure, at its usual horizon.

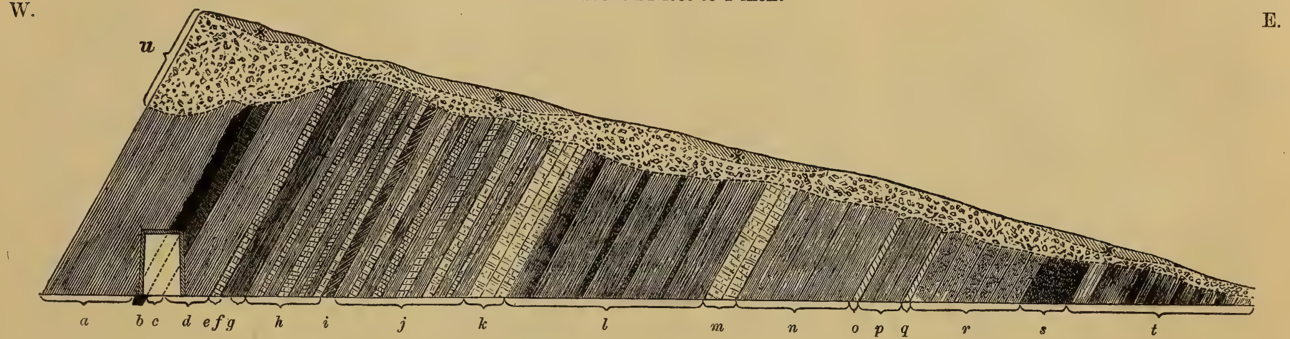
Sometimes, however, the bed divides, mostly into two, but sometimes, as in the Berwyn Mine, into three beds. When this division takes place, the dividing substance is the thin phosphatic limestone. The uppermost bed at such times dies out as it enters the overlying shales. So also does the middle one. It is invariably the lowest bed which is continued forward, the overlying limestone dying out until the shales take their true position immediately above the phosphorite bed.

It may help to the better understanding of the whole subject if I now describe generally the strata with which the phosphorite bed is associated. It lies, as I have said, at the summit of the Bala Limestone. At Blaen Rhiwarth, where the Berwyn Mine is situated, and at a depth of about 300 feet below the phosphorite, the limestone is seen gradually passing out of the ash-bed (which close by becomes a compact greenstone) and assuming a calcareous character. Its lower beds are massive and are charged here and there with their characteristic fossils. Higher up the beds become thinner and are interstratified with shales of various textures, until at last the whole deposit is capped by the phosphorite, and shales permanently follow.

To describe the fossils of the beds below the phosphorite would be to enumerate the whole of the fossils of the Bala Limestone. I would therefore now only direct attention to two or three features in the grouping of these, which are chiefly remarkable along with the phosphorite bed by their continuity over a large area.

Fig. 2.—*Section of Strata at the Berwyn Phosphorite Mine, west of Llangynog, North Wales.*

Scale about 21 feet to 1 inch.



a. Grey shale, with Echinoderms, phosphatized.
b. Phosphate bed.
c. Dark limestone impregnated with phosphate.
d. Dark shales with veins of sulphate of baryta passing upwards into a soapy clay.
e. Limestone, with veins of sulphate of baryta.
f. Dark shales.
g. Bluish grey limestones.
h. Limestones and shales, often pyritous, and decomposing towards the top as brownish sandstone, containing *Orthis* and *Leptæna* of several species, *Illænus*, and *Asaphus*.
i. Blue slaty bed.
j. Limestones and shales, with *Orthis*, *Leptæna*, *Bellerophon*, and other usual fossils in places.
k. Crystalline limestone.
l. Tough blue shaly rock, with calcareous partings; fossils here and there.
m. Limestone, with *Illænus*, *Orthis*, and other fossils plentiful.
n. Beds of bluish shale, with black balls of phosphate, small Trilobites, &c.
o. Kaolin.
p. Tough calcareous shales, fossiliferous.
q. Kaolin.
r. Alternation of slaty, calcareous, and arenaceous beds.
s. Limestone, composed almost entirely of *Orthis spiriferoides*.
t. Shaly beds, slightly calcareous, with limestone bands.
u. Superficial drift, local.
* Peat deposits.

About 60 feet below the phosphorite is a bed (see Berwyn section, fig. 2) about 5 feet thick, which is composed chiefly of *Orthis spiriferoides*, M'Coy. There are other fossils mixed with this, as *Asaphus*, *Illænus*, *Orthis grandis*, *O. elegans*, *O. expansa*, and others; but *O. spiriferoides* is by far the most prevailing form. This same fossiliferous bed, with its preponderance of *Orthis spiriferoides*, is found occupying the same position with relation to the phosphorite at Cwmgwynen (see that section, fig. 1) and Llanfyllin; and from this point it is continued S.E., towards Meifod and Guilsfield, where however the phosphorite bed has not yet been discovered, although, I doubt not, it may be found in its usual position.

A few yards below the phosphorite bed is another fossiliferous band, in which the most abundant fossil is *Orthis Actoniæ*. This is associated with *Asaphus* (*Powisii*), *Illænus*, *Lingula* (*tenuigranulata*), together with various species of *Orthis* and *Leptæna*. These occur in a very tough limestone, which has, however, sufficient iron in it to decompose where the edge of the bed is exposed to the atmosphere. This bed is very persistent in its character, so much so that I have been able by its appearance on the surface to drive through successfully to the phosphorite beyond.

Another bed which is continuous over the whole area is that of the "black shales" mixed with sulphate of baryta, which at a distance of from 3 to 5 feet underlies the phosphorite. From its less hardness, it is in the upper surface of this bed that the miners "hole" in working the phosphorite; so that the whole of the intervening thin limestones have to be taken down. In the year 1870, when on a visit to Penygarnedd, Prof. Morris and myself discovered Graptolites in this bed; and as soon as the Berwyn mine had been open, I naturally looked for them in the same bed there. There are at the latter place, however, two difficulties in the way of finding the Graptolites. The first is the highly-cleaved nature of the shales; and the second is the highly pyritized condition of any contained organic remains, so that it is impossible to find Graptolites in their usual form. They are present in abundance, however, as the numerous pyritized stems serve to show.

The "little limestone," as it is called by the miners, to which I have already referred as immediately underlying the phosphorite, is also a continuous bed. Its upper surface is sometimes covered with minute Brachiopoda and other fossils, among which, at Penygarnedd, there has been found *Calymene brevicapitata*.

Any organic remains which there may ever have been in the phosphorite bed itself have had their structure and form completely destroyed by the chemical changes which have taken place. I have, however, discovered in it what appear to be the remains of Orthoceratites and Lamellibranchiate shells.

The shales immediately overlying the phosphorite are rich in organic remains. These, when found in proximity to the bed, are all more or less phosphatized. In proportion to the degree in which this has taken place is the degree of the obliteration of the marks and original form of the fossil. At the Berwyn mine this process of phosphatization is most complete. At Llan-y-mowddwy, where sulphur largely takes the place of phosphate of lime, the nodules, which are there plentiful in the shales, are all oxidized.

At Cwmgwynen (see section, fig. 1) the approach to the phosphorite is from the upper side, consequently a good series of these overlying shales is traversed. It is there seen that as the distance is increased from the bed itself the fossils lose their phosphatic character. I have collected from these beds at Cwmgwynen *Echinosphœrites* (*balticus*), *Caryocystites*, and other Echinoderms, *Lingulœ*, *Modiolœ*, *Theca Forbesii*, *Cycloceras arcuatum*, and *C. sonax*, *Orthocerata*, *Illœnus Davisii*, and other fossils.

It will be seen by a reference to the sections that strata in which the deposit occurs are, throughout the region described, highly inclined, perpendicular, reversed, and contorted. On the whole, this nearly vertical condition of the strata is favourable to the processes of mining.

By a reference to the analyses which I append to this paper, it will be seen that the composition of the bed is very uniform over a large area, the picked samples at Cwmgwynen and Berwyn mines, yielding over 60 per cent., and the bulk of the beds, both at these places and at Penygarnedd, making 46 per cent. of phosphate of lime. In the neighbourhood of Llanfyllin, however, where the subjacent limestone becomes more arenaceous in its nature, the quantity of phosphate dwindles down, as at Green Park, to 20 per cent. An important change has also taken place in the composition of the bed before it emerges from under the Berwyn mountains, in its western outcrop, on the flanks of Aran Mowddwy. There sulphur has taken the place of the phosphate of lime, which is reduced to a minimum. I may here remark in passing, that the phosphorite bed has yet to be searched for, north of this point, along the western outcrop of the Bala Limestone, towards Bala.

In attempting to account for the existence of this bed, we cannot be far wrong, I think, in ascribing to it an organic origin. It is in all probability an old sea-bottom, on which the phosphatic matter of Crustacean and Molluscan life was precipitated and stored during a long period. Certain marine plants may also have contributed their mite of phosphatic matter; but the quantity furnished by them would, I think, be small. It is possible also that a great abundance of marine vegetation, taken with a deficiency of Crustacean and Molluscan life, may partly account for the altered character of the bed on its western outcrop. The abundance of vegetable which was evidently mixed up with the animal organisms of the period is evidenced by the quantity of graphite and sulphur which everywhere are present in the phosphorite bed.

I see no reason to alter the opinion expressed by me in the year 1867, in the communication to the 'Geological Magazine' already referred to, as follows:—"We may, I think, regard the phosphate bed as the remains of a laminarian zone of sea-life, just as the wide-stretching ferruginous sandy layers in the same formation, with their fossils often broken and confusedly huddled together, are the remains of the littoral zone of the same period."

If we consider how pulpy and gelatinous was the matter of which the creatures were made who swarmed in that early sea, and how light were their horny shells, and contrast these with the density, the compactness, and the high specific gravity of the deposit, 3·25, we shall be able to form some idea as to the length of the period that would be required for the formation of the phosphorite, which in its present greatly compressed state must be many times thinner than the deposit in its original condition.

Possibly it was in the earlier stages of the process of compression, and when there was but a comparatively light covering of mud above it, that the process of dull crystallization took place, which gathered up the phosphorite into the purer concretionary nodules of the whole deposit.

If now we were to bend back the edges of the strata at the Berwyn and Cwmgwynen mines, to a horizontal line, and piece them with the middle portion, which has been broken and denuded through the upheaval of the underlying traps and slates—if we further follow the phosphorite bed underground to where it comes up in an altered form on the flanks of Aran Mowddwy, and measure the length of the district described on the map by the breadth thereof, we shall gain some conception of the extent of the shallow sea, with its swarms of life, in which the bed was deposited, covering, as it does, an area of quite 140 square miles. Over this area the depth of the sea must have been nearly uniform, and the same conditions of life must have prevailed. Nor do we even now discern its uttermost limits; for I doubt not, as I have said before, that, in some shape or other, the bed may be found at the same horizon along the entire course of the Bala Limestone.

It will be observed from the analyses that there is little or no carbonate of lime in the deposit. Yet there are, as we have seen, the remains of shells, whose substance was carbonate of lime, on the uppermost face of the phosphatic limestone which immediately underlies the deposit, showing the existence of these after the phosphatic matter had begun to permeate the limestone in which they are imbedded. Again, we can hardly conceive of a condition of sea-life stretching, as this did, over a large area in which there lived only Mollusks and Crustaceans with horny phosphatic shells and shields. The curious question arises, therefore, What has become of the carbonate of lime of which the shells of their congeners were made?

In one of his essays the late Dr. Daubeny tells us that Schmidt found in the inner side of the mouth of *Unio* and *Anodonta* no less than 15 per cent. of phosphate of lime, 3 of carbonate of lime, and 82 of organic matter, from which the inference was drawn that the phosphate was separated from the blood by this organ for the purpose of cell-formation. The doctor adds, "It seems probable that the carbonate is converted in the animal into phosphate by the phosphorus it contains." Here, perhaps, we have a clue to the missing carbonate. The great preponderance of phosphatic organisms, with which the period covered by the deposit commenced, gradually absorbed and secreted all carbonate of lime, whether held in solution in the water or redissolved from the shells of dead mollusks; and so, turning it into phosphate, grew and multiplied exceedingly, and became at last almost sole masters of the position by this appropriation, until the supply of carbonate of lime became insufficient for their sustenance as the mineral conditions came on under which the overlying shales were deposited.

The more difficult question may be asked, What became of the phosphatic matter of the animals of the myriad shells that compose the fossiliferous layers in the Bala Limestone below the phosphorite bed? I would simply offer a twofold general answer to this inquiry: first, perhaps the mechanical condition of the seas was unfavourable to its quiet deposition; and, secondly, perhaps owing to its diffusion in the water, it was taken up by rapidly increasing succeeding generations of organisms, until, the sea-conditions becoming favourable, it was finally deposited on the sea-bottom as the deposit we have been considering.

The comparatively low percentage of phosphatic matter in the deposit, together with the cost of carriage to a railway, renders an economic working necessary. I think, however, that it is now proved that the deposit may be worked profitably. It is to be hoped also that with the introduction of tramways into the Welsh valleys, other portions of the deposit may be reached which are now practically inaccessible. Especially is this to be desired when we consider that we have thus in North Wales many millions of tons of fertilizing matter. The phosphorite is sent to chemical works as free as it can be made of extraneous matter. It is there treated with acids, which separate the phosphate of lime from the rest of the mass. This is then ready to be used in the composition of a variety of chemical manures.

In concluding this paper I may perhaps be allowed one reflection, which is this. To whichever side of geological inquiry we turn, we see the life of ages long since gone by ministering to the life of today. The world is ever being built of, and upon, the wrecks of past creations; and in the use made of the deposit we have been considering we have another illustration of the same truth. The low organisms of a Cambro-Silurian sea contribute the force of the nerve and the brain by which we are able to unravel the mysteries of distant cycles of time, to grasp the distant future, and to comprehend, to some extent at least, the wondrous economy of the universe.

Analyses of North Wales Phosphorite.

1. Cwmgwynen. General analysis given by Dr. Voelcker at the meeting of the British Association in Birmingham in the year 1864.

1st sample gave 64·16 of phosphate of lime.
2nd „ gave 48·50 „

"There was no carbonate of lime, some fluoride of calcium, alumina, and oxide of iron.

"The darker-coloured contained more graphite, and were richer in phosphate of lime than the lighter-coloured specimens."

2. Penygarnedd Mine. I am enabled, through the courtesy of the manager, to say generally that the bulk of the deposit here averages 46 per cent. of phosphate of lime.

3. Berwyn Mine. Through the kindness of Messrs. F. C. Hills & Co., of Deptford, I am able to give the following full analyses of the deposit at this mine, which I have developed from its commencement in February 1872.

A. Analysis of concretionary nodules by Mr. D. Hesketh Richards, of Oswestry.

Moisture and organic matter	4·200
Sand	22·600
Tribasic phosphate of lime	64·165
Oxide of iron and alumina	6·890
Other constituents not determined	2·145
	100·000

Another analysis of similar concretions gave 61·44 phosphate of lime.

B. Analyses of two consignments from the bulk of the deposit.

	I.	II.
Loss on burning	6·77	3·06
Phosphoric acid*	22·54	20·92
Lime	31·08	30·13
Oxide of iron and carbonic acid	19·12	22·88
Insoluble matters	20·49	23·01
	100·00	100·00

C. Five other analyses of the bulk of the deposit, made by Messrs. Hills, gave an average of 46·85 phosphate of lime. There was also in all the samples about ½ per cent. of copper.

Llanfyllin. Analysis made of the phosphorite bed near this town gives a range of from 20 to 30 per cent. of phosphate of lime.

Dinas Mowddwy and Llan-y-Mowddwy. Two samples from the deposit north-west of these villages gave the following proportions of sulphur and phosphate of lime.

Phosphate of lime	2·90	1·72
Sulphur	34·38	34·20

The rest is made up of sand, iron, and alumina.

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* Equal to tribasic phosphate of lime 49·207 45·67.

Discussion.

Prof. **Seeley** remarked that the concretionary character and dense structure of the nodules were possessed by them in common with the nodules in the Cambridge Upper Greensand; and although the latter nodules had no investing graphite, they often showed indications of vegetable origin. He thought that Mr. Davies had laid too much stress on the animal origin of the phosphate; for the geological deposits richest in fossils, such as Inferior Oolite or Cornbrash, do not contain more than 3 or 4 per cent. of phosphate of lime; and if its origin was as supposed, we should expect phosphatic beds to be much more numerous than they are in nature. The recent researches in the 'Challenger' have revealed facts which seem to have some bearing on this question. Foraminifera in falling through the water have their shells dissolved to some extent. Prof. Rogers, by noticing that greensands were forming in warm streams in the ocean, had rendered it probable that, while the process of solution was going on, the silicate of alumina and iron was being redeposited in other shells which had not yet fallen; and in falling some of them may become filled with phosphate of lime. This process might also lead to the deposition of a gelatinous mass of phosphates on the sea-bottom, which might ultimately be converted into the nodules. He said that he had ascertained that most marine plants would yield a considerable percentage of phosphate of lime, and he was therefore more inclined to accept the view that the phosphate in these deposits was due to vegetable organisms than to assign them an animal origin, especially as a large accumulation of phosphates would result from the growth and decay of banks of seaweed growing in one locality during long periods of time. Still he thought there may have been some unusual circumstances to lead to the formation of such deposits; and he had therefore argued in favour of there being an excess of phosphoric acid in the sea at that time, due to the denudation of apatite or other phosphatic matter of volcanic origin.

Mr. **Charlesworth** did not agree with Prof. Henslow's views as to the coprolitic nature of the phosphatic nodules, and was prepared to accept the notion of their being redeposited from dissolved apatite. The discovery of phosphatic beds in such early rocks as those of the Bala series seemed to him to be of the highest interest.

Mr. **Hawkins Johnson** observed that Dr. Pereira had shown that there was about 7 per cent. of phosphate of lime in the ashes of seaweed, which might suffice to produce the phenomenon.

Mr. **Warington W. Smyth** attributed the thin coating of graphite to the presence of graphitic schists of considerable thickness at that horizon. It was constantly the case that hard nodules, such as ironstones, presented the appearance of having undergone some rubbing process which gave their surface a polished and striated appearance. He therefore thought that these nodules had been aggregated together much in the same way as the well-known nodules in Carboniferous beds.

Mr. **D. Forbes** was inclined to believe, with Mr. Seeley, that the eruptive rocks were a source of the phosphoric acid, as his experience had shown him that all these rocks contain apatite in greater or less amount. Analyses which he had made of limestones, almost wholly composed of shells and containing Crustacea, showed so small an amount of phosphoric acid that he thought the amount of phosphorus contained in these organisms had generally been overrated. He asked the Fellows present where he could find reliable analyses of the shells of Mollusca and Crustacea, as he had met with very few.

Mr. GWYN JEFFREYS remarked that though the nacreous layer of the freshwater *Unio* and *Anodonta* may have so much phosphate of lime, marine shells, such as oysters, contain only about 1½ per cent., and the beds in question were stated to be not of freshwater but of marine origin. The shells of Crustacea might perhaps contain more.

24. *On the* OCCURRENCE *of* PHOSPHATES *in the* CAMBRIAN ROCKS. By HENRY HICKS, Esq., F.G.S. *With an Appendix on the* CHEMICAL ANALYSES *of the* ROCKS, by W. H. HUDLESTON, Esq., M.A., F.G.S., F.C.S. (Read February 24, 1875.)

IN a paper by the late Dr. Daubeny, F.R.S., in the Quart. Journ. Chemical Society, vol. vii., entitled "On the produce obtained from Barley sown in rocks of various ages," he endeavoured to prove, by experiments made with rocks from different parts of the Cambrian strata of North Wales, that there was an almost entire absence of phosphoric acid in the rocks of that age. Having failed to extract any phosphoric acid from these by direct analysis, he adopted the plan of testing the relative capacity of rocks of various ages to yield this ingredient to the crops which grew in them; and by this process he calculated that the Cambrian rocks did not in any case contain more than about $\frac{1}{300,000}$ part, some containing only $\frac{1}{1,000,000}$. The rock-specimens examined were taken from the slate-quarries near Bangor, the quarries of Llanberis, and from near Dolgelly, probably Lingula-flags. In addition to these, he experimented also with Skiddaw slate from Cumberland, and with micaceous slate from near Glasgow, and from them obtained only much the same proportions. From these results he was led to infer that the seas in which these deposits had accumulated contained little or no animal life, and that we had here approached the borders at least of the lower limit of organic existence, especially as there seemed in addition to be an almost entire absence of lime in any form. In the last edition of 'Siluria,' these views are prominently brought forward to prove that very few organic remains could ever have existed in the Cambrian strata; and it is further mentioned that "in subsequent researches Dr. Daubeny could detect no traces of phosphoric acid in certain specimens from the Longmynd (which fundamental rock of the Silurian region is no more altered than the overlying Silurian strata), whilst the Ludlow rocks contained as much of it as any of the younger fossiliferous rocks on which he experimented"*.

I have already shown, in papers communicated to the Geological Society, that these views as to the probable absence of life in these early seas have not been supported by subsequent researches in the Cambrian rocks, and that we have evidence now, in the occurrence of zones of fossil remains to the very base of these rocks, that certain

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* Until after this paper was written, I was unaware that Mr. D. Forbes, F.R.S., had published in the Phil. Mag. May 1857, analyses of Silurian and Cambrian Limestones, which showed results very different from those obtained by Dr. Daubeny. He does not give analyses of rocks of so early an age as those referred to by Dr. Daubeny and in the present paper; but there is one analysis of a limestone, probably of "Menevian" age, at Church Stretton, which gives as much as 0·56 per cent. of P_2O_5 and 63·10 of carbonate of lime. The other analyses include:—Llandeilo Limestone from Dinover Park, Llandeilo, P_2O_5 0·56; Bala Limestone, P_2O_5 0·16; Dudley Limestone, P_2O_5 0·46.

forms of animal life did exist, and in great abundance, in those early seas. It seemed questionable therefore whether Dr. Daubeny's results as to the absence of phosphoric acid from some of these rocks could be relied upon as in any way indicative of the general condition of the Cambrian rocks. To test this I recently made analyses of rocks from different portions of the Cambrian strata, selecting some beds which were known to contain certain forms only of organic remains, others in which different forms occurred together, and some which hitherto had proved to be unfossiliferous.

The results obtained tend to show that although some portions of the Cambrian rocks, like some series in comparatively recent formations, do not contain more than a mere trace of phosphoric acid, yet there are other portions of the strata, both underlying and interstratified with these beds, which give evidence of the presence of this ingredient in considerable quantity, it being equal in amount in some cases to that found in the very richest of the more recent deposits. It is evident, therefore, that the conclusions arrived at by Dr. Daubeny, and supported by so great an authority as Sir R. Murchison, are entirely fallacious when applied to the whole Cambrian epoch, and that they can now only be accepted for those special portions of the strata examined by him. The following analyses are sufficient to illustrate these facts, as they include rock-specimens from the very base of the Longmynd (or Harlech) group to the top of the Arenig group. Several of these analyses were made for me by my friends, Mr. Hudleston, F.C.S., and Mr. J. Hughes, F.C.S.

	P_2O_5 per cent.	
1. Lower red beds (Longmynd group) with *Lingulella primæva*.	0·30	H. Hicks.
2. Grey flaggy and purple sandstones, unfossiliferous (Longmynd group).	A trace only.	H. Hicks.
3. Grey flaggy beds (Longmynd group) with Trilobites (these beds contain a considerable amount of carbonate of lime).	1·50	H. Hicks.
4. Grey flags (junction of Longmynd group with Menevian group) containing fossils sparingly (carbonate of lime in considerable quantity).	0·50	H. Hicks.
5. Grey flags, very calcareous-looking (Menevian group), with abundance of Trilobites, but only a few other fossils (carbonate of lime as much as 50 per cent. in many parts).	From 2·00 to 4·00, in proportion to the amount of fossils present.	H. Hicks.
6. Dark grey and light blue flags (Menevian Group) with *Paradoxides Davidis* and other large Trilobites (carbonate of lime in some parts over 42 per cent.).	From 2·36 to 3·00.	J. Hughes.
7. The same bed, but from another part.	1·52	W. H. Hudleston.

	P_2O_5 per cent.	
8. The shell of *Paradoxides Davidis*, a fossil of large size, with as little matrix as possible.	20·00	H. Hicks.
9. The shell of *P. Davidis* with a little matrix attached.	17·05	W. H. Hudleston.
10. Lingula-flags with *Lingulella Davisii* from Whitesand Bay, St. David's.	0·50	H. Hicks.
11. Lingula-flags with *Hymenocaris* from near Dolgelly, North Wales.	0·60	
12. Tremadoc rocks, with some Trilobites, but with a great abundance of Brachiopods and Lamellibranchs, from Ramsey Island, St. David's (carbonate of lime in considerable amount).	1·50	H. Hicks.
13. Lower Arenig rocks from Whitesand Bay, St. David's, with Graptolites, &c.	0·25	H. Hicks.
14. Middle Arenig rocks from Whitesand Bay, with Trilobites in considerable abundance.	From 0·50 to 1·50, in proportion to the amount of fossils present.	H. Hicks.
15. Upper Arenig rocks from near Abereiddy Bay, with a few Trilobites, Graptolites, &c.	0·35	H. Hicks.

The analyses show that, of these very early rocks, those which appear to contain no animal remains have, as might be expected, the least proportion of phosphoric acid, that the rocks in which the Brachiopoda or Graptolites occur alone do not contain any very large proportion of that ingredient*, and that the rocks which contain the remains of Crustacea have invariably the largest amount of phosphoric acid. The Lingula-flag beds which were examined contained only Brachiopoda; and the proportion of P_2O_5 in them was therefore small. The Tremadoc rocks, made up in great part of the shells of Brachiopoda, but with many Crustacea in addition, contained it in larger quantities; while the beds of the Menevian, containing little else than Crustacea (which occur there in great abundance), showed a marked increase in the amount present.

From these facts it is natural to infer that the Crustacea were the chief cause of the presence of so much phosphoric acid in these early deposits, and that the Mollusca were considerably inferior to the Crustacea in their power of producing this ingredient. For the purpose of testing this fact I made analyses of the fossil shells of several of the Mollusca; and, with the exception of the Brachiopods *Lingula*, *Discina*, and *Obolella*, which have more or less of a horny texture, but are of small size in these early deposits, I find that the

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* The so-called horny shells of the Brachiopoda contain P_2O_5 in considerable quantity. Prof. Sterry Hunt found as much as 85·79 per cent. of phosphate of lime in the shell of *Lingula ovalis*; but in these early rocks the Brachiopoda are of small size, and do not occur in very great abundance; so the beds in which they occur alone are not usually rich in this ingredient.

proportion of phosphate of lime in each is exceedingly small. Recent shells of Mollusca also, as a rule, only contain it in very small quantity; while the recent Crustacea, such as the lobster, crab, and sea-crayfish, contain in their shell on an average from 6 to 7 per cent. of phosphate of lime. The animal matter of the latter is also known to contain a considerable amount of phosphoric acid. Mr. Hudleston's analysis of the flesh of the recent lobster gives 0·332, and of the lobster-shell 3·05 per cent of P_2O_5. Doubtless also the animal matter of the Mollusca contains phosphoric acid in some quantity; for the matrix in which some of the fossil shells are imbedded, and the casts I find, frequently contain more than is to be found in the shell itself. The great Crustacean (*Paradoxides*) which occurs in such abundance in the Menevian rocks, contains in its fossil shell as much as from 17 to 20 per cent. of P_2O_5, and hence a far greater amount than is found generally distributed throughout the rock in which it occurs. Doubtless this large Crustacean, in some cases over 20 inches in length, was also fully capable of producing all that is now present in these rocks; for we have no evidence of the existence of any other forms of animal life at this period which could produce it in any very considerable proportion. The Mollusca were very small and scantily distributed. The remains of sponges occur only as fine siliceous or pyritized spicules; and there is no evidence of much vegetable matter. We are therefore compelled to fall back on the Crustacea, which occurred in myriads in these seas, and which, having the power of casting off their shells frequently, must have added greatly to the deposits. Indeed most of the carbonate of lime, which is here also very abundant (being, according to Mr. Hughes's analyses, in the proportion of as much as 42·39 per cent. in some portions of the beds containing *P. Davidis*), was also in all probability deposited by them. In many of the little phosphatic nodules which are interspersed throughout these deposits, casts of bivalve Crustacea are frequently seen enclosed, thus making it probable that these nodules were produced chiefly through the decomposition of the soft tissues and shells of these animals.

It is evident that the shell of the Trilobite was thicker and contained a larger proportion of phosphate of lime than those of the other Crustacea which lived at this time; for in the rocks where the phyllopod Crustacea, for instance, alone occur (as the Lingula-flags with *Hymenocaris* and the Skiddaw slates with *Caryocaris**), the proportion of phosphate and also of carbonate of lime is much less than where Trilobites occur alone. I can only account for this by supposing that the shell of these phyllopod Crustacea must have been thinner and less rich in calcareous material; for where they occur they are as plentiful as are the Trilobites in some of their richest beds.

I have marked in the section (p. 372) the position of the beds in the "Menevian group" at Porth-y-rhaw which have already been examined for phosphoric acid. The degree in which it occurs

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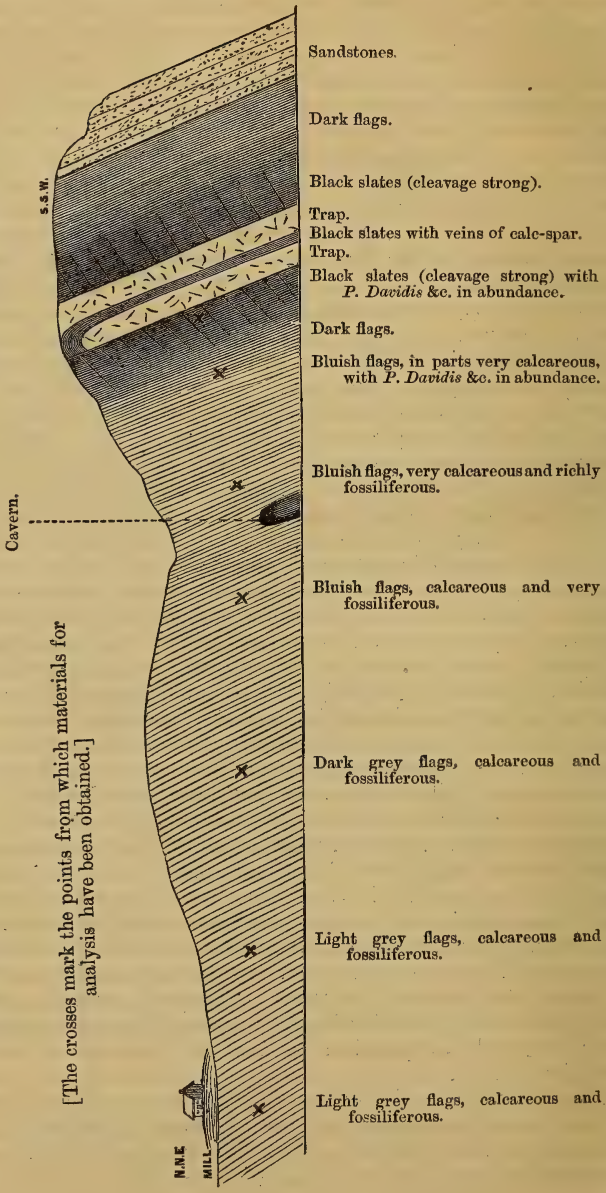
* Which I have been able to examine, through the kindness of Mr. Etheridge, F.R.S.



Section through the Menevian Rocks on the East side of Porth-y-rhaw Creek, near St. David's, including over 600 feet of strata.

[The crosses mark the points from which materials for analysis have been obtained.]

is found to be in exact proportion to the animal remains present —being in the proportion of less than ½ per cent in those which contain but few remains, and as much as 4 per cent in the richest beds. This, however, is only found to be true in regard to the beds which have not undergone any metamorphic change by contact with or proximity to intrusive dykes; for the beds which in this section yield the largest proportion of phosphoric acid are so altered in another section, from contact with an intrusive mass, that scarcely a trace of this ingredient is left in them, though fossils are there in plenty as impressions, but with none of their structure left. In this section, also, a similar change has taken place in the character of the beds near to the trappean masses. For some distance below and above the trap, the beds show an altered character: instead of being grey, hard, flaggy, and calcareous-looking, as are the other beds in the section, they gradually become black and slaty in character, and have a distinct slaty cleavage near the dykes. About a foot from the trap there is a very rich line of fossils, in which the large *Paradoxides Davidis* occurs plentifully; but here none of the structure of its thick shell is left, and its arched character is gone, the impressions being flattened and distorted. An analysis of portions of this bed where the fossils are most plentiful shows an almost entire absence of phosphoric acid and of lime, whilst these ingredients ought, according to the evidence derived by the analyses of other beds in which this fossil occurs, to have been present in large proportions.

When I made my first analysis of this rock I felt much puzzled at the absence from it of P_2O_5; and on mentioning the result to one or two chemical friends I was assured by them that it must be there, and that it would be found in combination with some other base, if not with lime. On repeating my analysis, however, with every care, I could not find it in any quantity; and I then placed portions of the rock, with the impressions of the fossil upon them, in the hands of Mr. Hughes and Mr. Hudleston, telling them at the same time of the opinions expressed. The result obtained by Mr. Hughes from the altered rock was phosphoric acid 0·096, equivalent to tribasic phosphate of lime 0·209; whilst another piece of rock unaltered, with *Paradoxides Davidis*, the same fossil, upon it, gave phosphoric acid 3·00, = tribasic phosphate of lime 6·54, or thirty times as much as in the altered bed, showing an extraordinary difference, and one which can only be accounted for by supposing some chemical change to have taken place sufficient to have set free the P_2O_5 from this rock. Mr. Hudleston's analysis also gave very much the same result, being only in the proportion of 0·11 per cent of P_2O_5 in the rock near the trap. The carbonate of lime, which was also determined by Mr. Hughes to be present in the proportion of 42·39 per cent. in parts of the unaltered rock, has also disappeared almost entirely from the altered slate. There can be no doubt, I think, that the phosphoric acid occurs in the unaltered rock in the state of tribasic phosphate of lime; and as this is known not to undergo a change from any amount of heat applied to it by ordinary processes, being fixed even in the fire, it seems probable that we must look for some other cause in addition to the heat, which would be capable of effecting this change. The extraordinary heat of so large a mass of melted matter, combined with the enormous pressure exerted at the same time upon the rock, may, however, have been capable alone of producing changes of which we have but little conception. Still I think it is probable that the change chiefly took place through the influence of watery vapour and gases generated at the time in the rock itself, or communicated to it from the intrusive vein.

The bedded rock, at the time this intrusion into it took place, was in the horizontal position, and doubtless in a plastic state and with many thousands of feet of other deposits superimposed upon it. These intrusive masses appear almost to follow the curves of the strata and to run in the direction of the line of the bedding along the coast; but they gradually get higher in the series in an easterly direction, and the direction of the flow seems evidently to have been from south-west to north-east.

Whenever the sedimentary beds come in contact with these trap dikes they always show an altered state; and as these masses can be traced for several miles, their effect on almost every bed of the Menevian group may be seen; for though the general direction is that of the line of bedding, yet in their course they gradually ascend and ultimately cross the series. The invariable effects produced are a deepening of the colour of the rocks, cleavage, loss of lime, of phosphoric acid, and of every evidence of such substances (as the horny texture of the shell of the Brachiopoda, the Crustacean shell, &c.), but with the fossil impressions left, in a compressed and distorted state. In addition to these changes, thin lines of iron pyrites are frequently seen running in the direction of the bedding in those beds which have undergone any considerable alteration in their character; and as, according to Mr. Hudleston's analysis, these altered beds are now deficient in pyrites, it seems evident that this must have been derived from them.

The analyses which I have made of portions taken from the intrusive dyke in the section at Porth-y-rhaw gave the following results:—(1) Under surface resting on black slate, P_2O_5 0·60 per cent, carbonate of lime 15 per cent; (2) Centre of mass, P_2O_5 0·40 per cent, carbonate of lime in small quantity only; (3) Upper surface of second mass, P_2O_5 0·50 per cent, carbonate of lime 8 per cent. Between the masses of trap there are, in black altered slate, veins of calcareous spar in a very pure state, and which when analyzed scarcely gave a trace of P_2O_5. From these analyses it will be seen that phosphoric acid is distributed throughout the whole mass of the trap, but that it and the carbonate of lime occur in very great excess towards the surfaces.

If these dykes in forcing their way through the beds did not take up some of the ingredients which they were directly or indirectly the means of setting free from these beds, it is but natural to suppose that they must have frequently, indeed usually, have had their composition changed and altered by the breaking-up of the rocks through which they were forced, and by the absorption of portions of these into their own substance. The phosphate and carbonate of lime in these masses may therefore have been obtained out of the rocks through which they were injected in the molten state; and these ingredients, in the condition in which they are found, may not have existed (or, at least, not in so large a proportion) in the intrusive mass prior to its meeting these sedimentary beds. This, of course, will not and is not intended to explain the origin of all the phosphoric acid in eruptive rocks; but it may nevertheless tend to explain the great preponderance present in some of the eruptive masses and the almost entire absence of it in others. In those passing through beds rich in organic materials we may naturally expect a preponderance; whilst in those dykes which, so far as we are able to judge, appear only to have met with barren strata, little should be expected; and I believe this is very much what is found to be the case.

The general conclusions which we seem to arrive at by these examinations and experiments are:—(1st) that animal life has been the chief means by which phosphate of lime has been produced from the very earliest time of which we are able to trace the record up to the present; that though all animal and vegetable life in the Cambrian and Lower Silurian seas contributed to its production, yet of the forms of life which are known to have lived during those epochs the Crustacea seem to have had by far the greatest share in its production, and of the Crustacea the Trilobites more particularly. Not only does it occur more abundantly wherever the Trilobites are present, but our analyses have proved that their shell, when preserved, contains an extraordinary amount of this ingredient, nearly one half being phosphate. The largest proportion known in recent Crustacea is that made out by Mr. Hudleston in the shell of the lobster—that is, 7·12 per cent of phosphate of lime; it is probable therefore that the Trilobites had a much larger amount in their shell than is to be found in recent Crustacea, where its place seems to be taken by carbonate of lime. We can hardly suppose, however, that the whole of the phosphate of lime which we now find to be present in the fossil occurred also in the natural shell; for during the process of decomposition of the animal matter, in which doubtless P_2O_5 occurred also in considerable quantity, the shell may have been made to undergo an important change, and a substitution have taken place. Still the great excess in the fossil compared with what is found in the matrix or generally throughout the rock leads one to suppose, especially when we take into consideration its comparative absence in the other fossil remains, that the natural shell did contain phosphate of lime in an unusual quantity. I am inclined to think that the shell of the Trilobite was of a more horny texture than that of the recent Crustacea, being somewhat of a character intermediate between the calcareous shell of these and the so-called horny shell of *Lingula*. Therefore, though it is useful to know the amount which by the analogy of recent Crustacea, the Trilobites may have been able to supply to the rocks, yet it would be most hazardous to rely on this test as in any way sufficient. The large proportion of phosphate of lime present in the Bala rocks is probably due to their containing, like the "Menevian" rocks, so large a number of Trilobites—these two formations containing them in greater abundance than any others.

Secondly, though it is possible that some of the more recent deposits may have derived a part of the phosphate of lime contained in them from apatite dissolved out of eruptive rocks, as recently suggested before this Society, yet on the other hand it is even probable that eruptive rocks derived phosphate of lime from the earlier sedimentary rocks through which they passed, and where it had previously been deposited by animal and vegetable life. We know of no eruptive rocks in this country of so early a date as the time when these "Menevian" beds were deposited. The dykes, which in some cases appear to run almost in the line of the bedding of these older Cambrian rocks throughout Wales, always alter the beds on both sides; and I do not think that any of them are of older date than the Upper Arenig or Lower Llandeilo epoch, in which we for the first time in the succession meet with truly contemporaneous tuffs and ashes. In Canada, however, it is said there are eruptive rocks of Laurentian age; but whether these contain phosphate of lime I do not know. The source from which the P_2O_5 was first obtained must of course still remain a difficulty, and we can only expect at present to unravel the mystery so far as the facts laid open before us in nature enable us clearly to do so. We can hardly do more than inquire into the processes by which this ingredient, so indispensable now to animal and vegetable life, was first separated from the sea, in which from the very earliest period it seems to have existed in a state of solution, and the means by which it was afterwards deposited in such large proportions in some sedimentary rocks. In an agricultural point of view the presence of so much phosphate of lime in some of the series of beds, as "Menevian" and "Middle Arenig," must be a matter of considerable importance; and I find, on looking over the geological map of St. Davids, that where these series occur they underlie the very richest land in that neighbourhood. The Middle Arenig series particularly shows this; for it is of greater thickness and extends in a more continuous line than the "Menevian," and this line from time immemorial has had a fame for the goodness of its produce, whether in stock or cereals.

APPENDIX. *On the* CHEMICAL ANALYSES *of the* ROCKS.

By W. H. HUDLESTON, Esq., M.A., F.G.S., F.C.S.

At the request of Mr. Hicks I made several analyses of Cambrian rocks, principally with the view of determining the amount of phosphoric acid in each; but incidentally, in one or two cases, an analysis, more or less complete, has been made of the specimen of rock itself.

No. I. is a darkish grey flaggy rock, with an impression of *Paradoxides Davidis* on one side. Portions of the slab immediately under the fossil have a somewhat nodular appearance. The entire fragment is bulged out by an interior lenticular thickening, which consists largely of calcic carbonate, whereas the layer in immediate proximity to the fossil does not effervesce much with cold acid. Hence this small fragment consists of two very different kinds of rock.

Small crystals of pyrites may be observed. The specific gravity of the fragment is 2·84.

The following analysis represents chiefly the composition of that portion which adjoins the fossil impression and which does not effervesce strongly in cold acid; it is not, however, altogether without some of the interior and more calcareous portion.

	per cent.
Silica, insoluble silicate, and pyrites	62·47
Oxides of iron (calculated as ferrous oxide)	12·37
Alumina	7.78
Lime	3·27
Magnesia	2·25
Phosphoric anhydride	1·62
Difference, chiefly carbonic acid *	10·24
	100·00

It is worthy of remark that there is a curious reddish brown extractive matter which pervaded this analysis, and that a very similar substance also pervaded the analysis of the lobster-shell, hereafter to be noticed.

No. II. Specimen in contact with trap. A dull black slaty rock, joints lined with ferric hydrate, no pyrites visible. The impression upon it of a Trilobite is distinct; but there are no indications along the costæ of the decomposition of pyrites as in No. I. Neither is there any lenticular thickening. The fragment is homogeneous. No effervescence with cold acids; some soluble silica. Specific gravity 2·69.

	per cent.
Silica and insoluble silicate (hardly any pyrites)	81·44
Oxides of iron (calc. as ferrous oxide)	5·56
Alumina	4·26
Lime	0·44
Magnesia	1·92
Phosphoric anhydride †	0·11
Difference, chiefly water ‡	6·27
	100·00

There is none of the reddish brown extractive matter noticed in the analysis of No. I.; but the insoluble residue before ignition is

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* Containing, besides, water, organic matter, a very little alkali, and traces of sulphuric acid.

† The rock, when fused, exhibits no material increase of phosphoric acid.

‡ With some organic matter, carbonic acid, and alkali.

very black. There is evidently an amount of carbon, which tends to darken the colour of the rock.

No. III. Another specimen of unaltered Trilobite-flag. It is much darker in colour than No. I., and does not effervesce in the cold. It is thin-bedded, and has Trilobite-remains on both sides, portions of the shell being in some cases preserved. There is much pyritization in the vicinity of the fossil; and the partial oxidation produces seams and stains of ferric hydrate, especially about the furrows between the costæ. The portion underneath the glabella is a honey-combed mass of partially oxidized pyrites. Specific gravity 2·77. There is a large amount of phosphoric acid in the outer skin of this specimen, but hardly any lime carbonate. This shows that phosphates and lime carbonates are not necessarily inseparable. There is, however, a considerable amount of ferrous oxide, which may perhaps have replaced the lime. The qualitative analysis shows sulphur in great quantities, and traces of manganese.

No. III*. "Shell with a little matrix." This is a still more superficial scrape from a specimen similar to the last. It contains large quantities of phosphoric acid, as the subjoined partial analysis will show.

	per cent.
Insoluble, much pyrites	30·85
Phosphoric anhydride	17·05
Lime	abundant.
Ferrous oxide	abundant.
Magnesia	not much.

The phosphates in this specimen, calculated as ordinary calcic phosphate, amount to more than half the soluble matter; it is not improbable that some chloritic, glauconitic, or serpentinous silicate is also associated. There are indications of this likewise in Nos. I. and II.

No. IV. "Trap." Fragment from the core. Distinctly crystalline. Felspar crystals; small twins of orthoclase. The amphibolic element is in a decomposed and hydrated condition. It contains patches and stains of ferric hydrate, and little irregular vacant spaces (not vesicles, however), is easily crushed and evidently far advanced in decomposition. Crystals of pyrites visible. No effervescence in the cold. Specific gravity 2·59. This is less than that of any of the sedimentary rocks, I., II., or III., and is all the more remarkable as the specimen contains nearly 10 per cent. of the oxides of iron. The undried powder yields to hydrochloric acid 25 per cent.; and if we add an equal amount of silica in combination, half the rock is attacked by acid. Of the soluble bases there is 7·71 per cent. ferrous oxide to 1·55 per cent. ferric oxide. The rock loses much water on ignition; it contains (in the soluble bases) but little lime, though large quantities of magnesia. All these facts point to a serpentinous condition of a large portion of this trap. The partial fusion of the insoluble residue shows both soda and potash.

	per cent.
Phosphoric anhydride	0·323

For the purpose of instituting a comparison, the following analyses of lobster were also made:—

	per cent.
Lobster-shell dried at 100° C. contained of phosphoric anhydride	3·26
Lobster with shell weighing 566 grms. contained 4·3 grms. of phosphoric anhydride, equal (on the entire weight) to	0·76

This rate would give to a ton of boiled lobster, with the shell, about 17 lbs. phosphoric anhydride.

Lobster-flesh (boiled), calculated on the entire weight, contained	0·332

As these two latter analyses were not calculated upon the substance dried at any definite temperature, they cannot be deemed to have any scientific value, so far as the actual percentage of phosphoric acid is concerned; but as rough experiments showing the amount of phosphoric acid which a dead Crustacean buried in sediment might be expected to yield in proportion to its weight, these analyses may be of geological interest. The second analysis would seem to indicate that a lobster would contribute phosphoric acid (anhydride) equal to about $\frac{3}{4}$ per cent. of its total weight. The shell contains far more in proportion. A French chemist some years ago gave the following analysis (Fremy, Annal. Ch. Phys. 3, xliii.).

	calc. phos.	calc. carb.	org. mat.	Total.
Sea crab.......	6·7	49·0	44·3	100
Land crab	6·7	56·8	36·5	100

The amount of calcic phosphate agrees pretty well with that found in the lobster; and it is rather singular that, according to the analysis quoted, whilst the carbonate of lime varies so materially in the sea and land crab, the calcic phosphate is the same in both.

Reasoning from the analogy of existing Crustacea, therefore, one would say that about 3 per cent. of phosphoric acid (anhydride) might be expected to have existed in the shell of the ancient Trilobite, unless the shell, as suggested by Mr. Hicks, had a somewhat different composition, and that the very great excess of phosphoric acid which some of these Trilobites exhibit in the fossilized condition is due to the ordinary processes of substitution, when, as in the pseudomorphs of mineralogy, one salt replaces another more or less completely in the fossil. In this case the excess of phosphoric acid now found in the shell of these Menevian Trilobites would be derived in part from the phosphoric acid once existing in the flesh of the animal itself. From the same source also, viz. the flesh of the animal, would be derived the sulphur which now, in the form of pyrites, is so much associated with the phosphatic matter of these beds.

It is evident, then, that there exists a considerable amount of phosphoric acid in certain portions of the Cambrian rocks; moreover this is associated with the large Trilobites in a remarkable manner.

The very small amount of phosphoric acid found by Dr. Daubeny in the apparently unfossiliferous portions of these rocks in North Wales appears to have been in a remarkably soluble form; for as on the one hand the dolomite of Roche Abbey, which is probably crystalline, yielded during the first year no more phosphate in the barley-ash than did the Cambrian slate of Dolgelly, still in the second year, whilst this latter was entirely exhausted, the dolomite yielded about three times as much phosphoric acid in the barley-ash as it had done in the first year. This points to the probability of the phosphate in the Cambrian rocks under examination having been in a readily soluble form; and this, indeed, is a conclusion towards which the analysis of Mr. Hicks's specimens of Menevian flags also draws us. Subcrystalline limestones and dolomites may, then, hold their phosphate in a more crystalline, and therefore less soluble, form—not unlikely as chlor-apatite. Apatite generally is stated by Bischof to be about three hundred times less soluble in carbonated water than some varieties of non-crystallized calcic phosphate. We may therefore legitimately infer that the phosphate of the Cambrian rocks, as far as we have analyses of these, does not exist in a crystalline form.

This brings us to a consideration of the source of the phosphate in the Menevian beds—and incidentally to that much-vexed question, the origin of phosphatic accumulations in the successive formations. In the Trilobite-flags this must be, as suggested by Mr. Hicks, largely due to Crustacean remains, both flesh and shell containing, as we have seen, a considerable quantity of phosphoric acid. It is of course impossible to say with absolute certainty what proportion of phosphoric acid the great Trilobite of St. David's contained in his shell; and, indeed, we should require a large series of analyses of several orders of existing Crustacea before we should be in a position to decide as to whether the percentage differs materially in the several orders. But we may fairly say that, having once established the fact of Crustacea being rich in phosphoric acid, the more bulky forms would yield a richer deposit, because, even supposing their percentage to be the same as that of the smaller forms, their buried bodies would displace a greater amount of sediment, and on the putrefaction and ultimate disappearance of their organic constituents, their mineral residuum or ash, consisting chiefly of phosphates and sulphides, would bear a greater ratio to the ordinary sediment than in the case of a smaller creature taking up less space. At the same time these Crustacea would derive their phosphoric acid, as well as all other constituents, from their food; and therefore such animals can, for geological purposes, be only viewed as collectors in a well-concentrated form of substances existing more diffusedly in other organisms.

The primary origin of phosphoric acid, if it is necessary to go so far back, must naturally be sought in minerals which are decomposed by aqueous and atmospheric solvents, whereby their phosphates are rendered available to plants and, through these, transferred to animals. But the commencement of this cycle of events is to be read in a volume of geological history to which we have no access. The geological record is like the Sybilline Books: none can say what is the number of the volume, reckoning from the beginning, which we are to assign to that containing the history of the formation at present under consideration. It must, however, be granted that at that particular stage of the earth's history which we call Cambrian a considerable amount of organic progress had already been made, and that abundance of nitrogenous food rich in phosphates was then at the command of the great Trilobites.

But we do not suppose that Crustacea were the only centres from which phosphatic accumulations were derived at this time. Wherever organic matter, containing nitrogen in the proportion usual in protein compounds (albuminous principles), was decaying, whether the organization was simple or complex, animal or vegetable, it is certain that an amount of calcic phosphate would be set free. It would be useless to quote the numerous analyses bearing on this subject; but, as a rule to be deduced therefrom, it may be stated that the ash of protein compounds consists for the most part of phosphates. These being comparatively fixed substances, would tend to accumulate in the various sediments at the bottom of the ocean; whilst the elements more readily volatilized, the carbon, the hydrogen, the nitrogen, and the oxygen, in various gaseous combinations would, during the process of putrefaction, escape, and be held for the most part in solution in the overlying waters. This easily serves to account for the presence of disseminated phosphoric acid, though of course the salts (usually of calcium) of which it forms the acid element undergo endless modifications, according to the solvents and reagents to which they are exposed. Thus it often happens that phosphates are largely accumulated round certain bodies in the various strata; and numerous theories have been brought forward to account for this. Some have thought that a gelatinous phosphate has been precipitated from highly phosphatized waters by ammonia generated through organic putrefaction. This takes place in a soil; but such action, by rendering the phosphates immediately insoluble, would tend to random precipitation unfavourable to aggregation round a centre.

Bearing in mind that chloride of sodium increases the solubility of calcic phosphate in carbonated waters, we may well imagine that an appreciable amount of calcic phosphate occurs in solution in the bottom water of the sea, where the quantity of carbonic acid is notoriously greater than in the upper layers. (Incrustations of steamboat boilers, taken even from the upper layer, but possibly in shallow places, have yielded 0·04 per cent. of phosphoric anhydride.) Such phosphate would be derived principally from the undeposited residue, the result of putrefaction of nitrogenous bodies, as previously stated. In this condition it would be very apt to combine with any albuminous body, more or less buried in the ooze, which was softening previously to decay. Indeed we know that chemical compounds of albumen and of gelatine are made which contain, in the case of the former, as much as 30 per cent. by weight of calcic phosphate.

Casein too, in coagulation, will carry down about 6 per cent of calcic phosphate in the presence of free acid. This latter fact is adduced to show that a slightly acid condition of the bottom-water and of the fluids in the pasty mass which is the embryo of the future formation may be deemed essential to the production of phosphatic nodules.

The second portion of Mr. Hicks's paper opens up a larger and far more difficult question, viz. as to how far an intrusion of trap may deprive a sedimentary bed of phosphoric acid. In the case he adduces (see Analysis No. II.) it is clear that a Trilobite-bed in contact with a trap is more or less deficient, as compared with other Trilobite-beds of the same series, in phosphoric acid, which presumably may have been there. The rock is also very poor in lime, containing not quite one half per cent. of its entire mass, as far as this can be dissolved by acids. The absence of the extractive matter alluded to in the analysis No. I. also points to considerable alteration, as does the carbonized condition of the organic matter in the slate, and the almost total absence of pyrites in the body of the slate, whilst great plates of this mineral occur in some instances along its junction with the trap.

It seems reasonable to suppose that this particular bed may not always have been so poor in phosphate in comparison with the other Trilobite-beds of the series; and if it is always found that these beds, though showing the form of the Trilobite, yet contain in the vicinity of the trap but little phosphate, it is a legitimate inference that the trap must have had something to do with this disappearance.

But of course there is nothing new or extraordinary in a trap or any other intrusive or igneous rock taking up and appropriating to itself portions of the rocks through which it passes. This is easy enough to understand, as far as the portion of sedimentary rock which is actually received and incorporated into the substance of the invading mass is concerned. The difficulty is, to make out by what process certain substances in the adjoining sedimentary beds, not so incorporated, can have been transferred to the body of the trap itself. In this case, for instance, it will be asked by what means has the calcic phosphate been removed from the altered slate and transferred to the trap, as is alleged to have been the case. It will be remembered that the core of the trap contains at least three times as much phosphoric acid as the Trilobite-bed through which it passes; whilst the exterior of the trap, according to Mr. Hicks's analysis, contains a still greater proportion.

The chemical geologists, with Bischof at their head, are by no means in favour of the isolation of phosphorus, "which would involve complicated operations, the conditions requisite for which are not likely to occur in the chemistry of geology." Indeed calcic phosphate resists decomposition by heat better than most salts. There can be little doubt, however, that the contact of igneous rocks with sedimentary beds does in some degree extract the phosphates from these latter.

Bischof is in favour of removal by solution in the wet way, and instances the very large quantities of phosphates of lime and of alumina in the Carlsbad waters. Still he admits that phosphoric acid is more plentiful in recent than in old lavas, though the latter more frequently contain apatite. This looks very much as if the wet way tended in some cases to deprive igneous rocks of their phosphates. Thus it may be that this trap at one time contained more phosphoric acid than it now does; for the whole rock is evidently in a very altered condition. The outside is largely mixed with calcite, whilst the interior (see Analysis No IV.) is half made of a hydrated silicate, soluble in acid, of which the principal bases are ferrous oxide and magnesia, pointing in the direction of serpentine.

In this case it must be admitted that there are not sufficient data whereon to base correct conclusions; but a more detailed examination of the various points of contact between igneous and sedimentary beds, together with careful analyses of each, both close to and at a distance from the point of contact, might help towards the formation of a reasonable hypothesis which should explain some of the phenomena at present so puzzling.

Discussion.

Prof. Maskelyne said that the solution of the question of the diminution of the phosphate of lime near intrusive rock was easy. The intrusive rock in cooling would contract, and thus facilitate the percolation from above or the forcing up from below of water, which, flowing through the adjacent rocks, would dissolve out the phosphate of lime. He remarked that north of Cardigan Bay pisolitic iron-ore was found charged with phosphate of lime.

Mr. D. Forbes stated that when, many years ago, Dr. Daubeny maintained that the Cambrian rocks only contained mere traces of phosphoric acid, he had published (in 1857) chemical analyses of some of the oldest limestones then known, showing that these contained quite as much phosphoric acid as recent ones. He considered that the larger proportion of phosphate of lime found in the fossil Crustacea, as compared with the recent, was mainly due to the fact that, besides the organic matter, carbonate of lime had also been removed from them, and that the reason of the casts of *Paradoxides* near dykes of igneous rock containing only traces of phosphoric acid and lime was rather the removal of these substances by water than the igneous action of the dyke. He could not agree in believing that the phosphoric acid found in eruptive rocks was derived from the sedimentary fossiliferous beds through which they passed, but regarded it as an inherent constituent of the eruptive rock itself. Even the Menevian and Laurentian rocks were, after all, only made up of the débris of previous eruptive rocks; and he looked upon the eruptive rocks as the original source of all the phosphoric acid assimilated by animal and vegetable life. He regarded this paper as a most valuable contribution to geological science.

Mr. Koch inquired whether any Vivianite had been obtained by Mr. Hicks.

Prof. Seeley thought that the paper, interesting as it was, did not bring us any nearer to the source of the phosphate of lime in phosphatic deposits, especially such as those recently described by Mr. Davies as occurring in the Bala beds. The proportion of phosphoric acid in the ash of the lobster did not appear to be greater than in that of plants; and whilst the débris of marine animals would be rapidly dispersed, those of seaweeds would remain at the bottom, and it was to these that he was inclined to attribute the accumulation of phosphate of lime in these deposits. At the same time he believed that the phosphoric acid was primarily derived from volcanic rocks, out of which the phosphates have been washed by water. The great proportion of phosphate of lime in the shell of the Trilobite was probably due to infiltration.

Mr. Hughes said that he had examined many soils in Australia and elsewhere, and that when the soil was deficient in phosphate of lime the underlying rock was the same, but when the soil was rich in phosphate the rock also contained it. He had also found phosphoric acid in igneous rocks from the north of England and Scotland.

Mr. Topley inquired as to the amount of phosphoric acid in the flesh of the lobster. He remarked that the shells of the Gault were largely phosphatized, and that they seem to have drawn their phosphoric acid from the surrounding rock. There are many phosphatic nodules in the lower part of the Gault, and also on the surface of the Kentish rag.

Mr. Hicks, in reply, said he thought it possible that water, or rather watery vapour, may have washed out the phosphate of lime from the altered beds; but he contended that this must have taken place at the time the intrusions occurred, for at present these beds are as solid and impervious to water as are the beds in which the phosphate of lime is now present. He stated that he did not intend to say that there were no contemporaneous traps of so old a date as the Menevian beds, but that there were none in Wales of earlier date than the Arenig or Llandeilo series; he had even mentioned that there were some in Canada of the age of the Laurentian rocks; but as there was no evidence of any of these in Wales, we could not look upon the phosphate of lime in these beds as having been obtained from dissolved apatite. In reply to Prof. Seeley, he said he could not allow that some beds lost all their phosphate of lime by percolation of water, and that the fossils in the others obtained it by the same means. He did not suppose, however, that all the phosphate of lime present in the fossil shell occurred in the natural shell; and he believed that it had to some extent in the process of fossilization replaced carbonate of lime.

Mr. Hudleston, in reply to Mr. Topley first, said that his calculations of the percentage of phosphoric acid in the lobster were based upon the amount compared with the total contents of the animal itself, as this seemed the most suitable for purposes of geological inquiry. That ratio once established, other calculations might be made. The phosphates in these as in other sedimentary rocks must be regarded as a sort of residuum or ash, the result of the decomposition of nitrogenous organic matter which was left after the more volatile carbon, hydrogen, nitrogen, and oxygen had, under various combinations, more or less completely disappeared. Calcium phosphate is known to be the chief constituent of the ash of most albuminous principles: analyses of these were quoted. The question of the loss of phosphoric acid in the rock adjoining the trap was one of much difficulty; but as an instance somewhat similar, Bischof was quoted to the effect that large quantities of calcium phosphates occur in basalt in the vicinity of a guano deposit at the Isle of Ascension.

25. *On the* ORIGIN *of* SLICKENSIDES, *with* REMARKS *on* SPECIMENS *from the* CAMBRIAN, SILURIAN, CARBONIFEROUS, *and* TRIASSIC FORMATIONS. By D. MACKINTOSH, Esq., F.G.S. (Read February 24, 1875.)

[Abstract.]

WHILE admitting that the sides of many fractures have been coated with foreign substances, the author's observations led him to believe that true slickensides, or polished and smoothly striated surfaces, have been produced by the movement of one face of rock against another, *accompanied by partial* fusion*. In the case of many of the specimens, the surface had apparently been metamorphosed by heat resulting from pressure, as the whitened and hardened coating graduated imperceptibly into the ordinary structure of the rock. In some cases sandstone had apparently been converted into quartzite. He ventured to bring "the theory of metamorphism by heat in the case of many slickensided surfaces" before the Society, in expectation that it might lead to further investigation.

DISCUSSION.

Mr. SORBY said that while some facts seem to indicate the action of heat, there are many reasons which apparently show that the operation of that agent is unlikely. He believed that many actions and causes which we do not at present understand have been at work in producing slickensides. The subject deserved careful study.

Mr. FORBES could not agree with the author of this paper that the phenomena of slickensides were due to a partial fusion of the sides, since he had observed some of the very finest examples of slickensides on pyrites in the great deposits of Rio Tinto; and as this mineral was in a perfectly unaltered condition, it is evident that no heat reaching to any thing like its fusing-point could have been developed; nor could this be the case in limestones or in hydrated rocks, both of which would be altered in chemical composition if strongly heated. It would also be the same with the slickensides seen in the cinnabar from Borneo and Almaden, which mineral sublimes if exposed to even a comparatively gentle heat.

Prof. TENNANT said that at Matlock galena showed the same appearances.

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* Since this paper was read and discussed, the author has seen reason for restricting the term "partial fusion" to certain cases. He has lately found that Mr. John Aitken, F.G.S., of Bacup, advocated metamorphism amounting to vitrification by heat, as the cause of slickensides in 1873 (Proc. Manchester Geol. Soc. vol. xii.). and that Professor Marsh, of Yale College, U. S., in 1867, regarded slickensides as "friction-marks," and the accompanying coating as "merely a portion of the rock finely divided and compressed" (Proc. Am. Association of Science).—D. M., June 1875.

Mr. Dowker remarked on the production of slickensides in clay from movements due to alternate expansion and contraction by moisture and drought. He also showed the occurrence of a similar phenomenon in a crystalline mass found in a cavity of the Chalk.

Mr. Koch remarked that slickensides may be seen in coal, in which case heat could have had no action.

Prof. Rupert Jones inquired why mere rubbing might not have been the cause as in artificial polishing.

Prof. Seeley referred to some examples of artificial slickensides caused by striking and rubbing.

26. NOTES *on the* COMPARATIVE MICROSCOPIC ROCK-STRUCTURE *of some* ANCIENT *and* MODERN VOLCANIC ROCKS. By J. CLIFTON WARD, Esq., Assoc. R.S.M., F.G.S., of the Geological Survey of England and Wales. (Read November 4, 1874.)

[PLATES XVII. & XVIII.]

CONTENTS.

Introduction.—The object of the present paper (submitted to the Society with the permission of the Director-General of the Geological Survey) is, by comparing the microscopic rock-structure of several distinct groups of volcanic rocks, to gain an insight into the original structure of some of the most ancient, and therefore probably the most altered, members of the volcanic series. My desire has been mainly to note the relations of the component minerals to one another, and thus glean facts in the history of the rocks which they compose. For this purpose I have endeavoured by coloured drawings to render as truthfully as possible the microscopic structure of most of the examples brought forward. I have to acknowledge the very kind and willing assistance rendered by Mr. Allport in helping me to take up and prosecute to a small degree this line of research.

I. HISTORY OF THE SUBJECT*.

Very little, comparatively, has as yet been done in England on this subject; but perhaps some of the most valuable work that has as yet been effected in microscopic geology is the result of the labours of our countrymen Sorby and Allport.

In 1858, Sorby brought out his celebrated paper on the "Microscopical Structure of Crystals"†. He describes the glass, stone, and gas- or vapour-cavities in the minerals of the pitchstones of Arran, the lavas of Vesuvius, and some of the basaltic rocks of Scotland. Remarking on the great alteration which has been effected in the ancient trap-rocks during the course of ages, he nevertheless observes (p. 479), "The characteristic structure of the minerals of which ancient trappean rocks are composed is therefore so analogous to, or even identical with, that of the constituents of modern lavas, that the purely igneous origin of these ancient lavas appears to me to be completely established; but, at the same time, their present aspect is often to a very great extent due to the subsequent action of water." With regard to rocks formed at a high temperature, the author's chief conclusions are as follows:—"At one end of the chain are erupted lavas, indicating as perfect and complete fusion as the slags of furnaces; and at the other end are simple quartz veins, having a structure precisely analogous to that of crystals deposited from water. Between these there is every connecting link; and the central link is granite" (p. 496).

In 1867 an article appeared upon "the Microscope in Geology"‡, written by Mr. David Forbes. The author shows how the different minerals in volcanic rocks may be distinguished from each other by means of the microscope, and gives figures illustrating the general microscopic structure of the following rocks:—lavas of Etna, Vesuvius, and Tahiti; pitchstone dyke of Arran; Staffordshire basalt, and "white horse" dykes; diorite from Chili; uralite porphyry from

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* Reference will here only be made to those papers, or parts of papers, which bear upon *volcanic* rocks.

† Quart. Journ. Geol. Soc. vol. xiv. pp. 453–500.

‡ Popular Science Review, vol. vi. pp. 355–368.

Tyrol; quartz trachyte, and another volcanic rock from Peru; and some few metamorphic and sedimentary rocks.

The first of a series of valuable papers by Mr. Allport appeared in 1869 *; in it the author described the basalt of S. Staffordshire, and noted the presence of pseudomorphs after olivine. In the following year the same author contributed a paper on the "Basaltic Rocks of the Midland Coal-fields" †, showing that the traps of "Kinlet and Shatterford (west of Kidderminster), the Clee Hills, Little Wenlock (near the Wrekin, in Shropshire), Coalville (near Bardon Hill, in Leicestershire), and Matlock (in Derbyshire)," were all basaltic. In another paper, in the same year, upon the "Microscopical Examination of Rocks and Minerals" ‡, Mr. Allport showed that the traps of the Warwickshire Coal-field contain hornblende instead of augite, and are therefore true diorites; at the end of the paper the author states his belief "that the following results of microscopical examination will stand the test of further study:—

"1. The mineral constituents of the melaphyres and other fine-grained igneous rocks may be determined with certainty, a result which has not been attained by any other method of examination.

"2. The mineral constituents of the true volcanic rocks, and those of the old melaphyres, are generally the same.

"3. The old rocks have almost invariably undergone a considerable amount of alteration; and this change alone constitutes the difference now existing between them and the more recent volcanic basalts."

In 1871 Mr. Allport again contributed two papers, one "On the Microscopic structure and Composition of a Phonolite from the 'Wolf Rock'" §, and the other on the "Relative Ages of Igneous Rocks" ‖. In the former, the structure of the rock is shown to be similar to the Tertiary Phonolites, and an analysis is given. In the latter the author concludes "that there is no essential difference between eruptive rocks of different geological epochs," and states, "I arrived at this conclusion more than three years since."

In the same year (1871) Prof. Zirkel published a valuable memoir entitled "Geologische Skizzen von der Westküste Schottlands" ¶, in which he gave descriptions of the microscopic structure of many of the volcanic rocks of the western islands.

In 1872 follow papers by Mr. Allport "On the Microscopic Structure of the Pitchstones and Felsites of Arran" **. At p. 537 the bases of the pitchstones and the felsites are contrasted—the former being "*a homogeneous glass without a trace of double refraction*," the latter having a *felsitic* structure which "*invariably exhibits double refraction*," and "as either of the prisms is rotated, the mass appears to break up into variously coloured little patches, which gradually assume a more definite form as the axes approach to a right angle." None of the rocks described, however, seem to be con-

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[*] Geol. Mag. vol. vi. p. 115.

[†] Ibid. vol. vii. pp. 159–162.

[‡] Ibid. vol. vii. pp. 431–435.

[§] Ibid. vol. viii. pp. 247–250.

[‖] Ibid. vol. viii. pp. 448–450.

[¶] 'Zeitschr. d. deutschen geologischen Gesellschaft,' Jahrg. 1871, pp. 1–124.

[**] Geolog. Mag. vol. ix. pp. 1–9 and 536–545.

temporaneous traps, or they are not recognized as such. One felsite dyke in Auchenhew Hill is compared to rocks of the modern trachydolerite group. In conclusion, the author urges the abandonment of such terms as "porphyry" and "porphyrite" as *generic* terms, and deprecates "the distinction now made between rocks of different ages, when there is really no essential difference between them" (p. 544).

In 1872 Prof. Hull contributed notes on the microscopic structure of some trap-rocks to the Government-Survey Memoir on Sheet 48 (Ireland).

A paper by the same author "On the Microscopic Structure of the Limerick Carboniferous Trap-rocks (melaphyres)"* in the year 1873, describes them as representatives of the more recent basalts, but points out a distinction between them and the Tertiary basalts of Antrim, thus:—

Limerick. *Carboniferous.*

Base, colourless glass, containing	Augite crystals, Triclinic felspar, Magnetite, Olivine (pseudomorphs), Calcite and Chlorite (accessories).

Antrim. *Tertiary.*

Base, augitic, containing	Triclinic felspar, Titano-ferrite, Olivine (sometimes), Chlorite (sometimes).

In the Limerick traps he notes "the glassy felspathic base with cells and tubes," "the small quantity of augite," "the abundant infusion of chlorite," and "the abundance of calcite, also due to percolation." The occurrence of hornblende with some of these augitic rocks is also to be noticed. The author remarks in conclusion that his observations tend rather to confirm the opinion of Mr. Forbes, as expressed in his paper "Researches in British Mineralogy" †, viz. that "when the geological epochs of the appearance of two or more intrusive or eruptive rocks are known to differ, these rocks will then also be found to differ essentially in mineral constitution." This paper drew forth a reply from Mr. Allport in the following month‡, entitled "Tertiary and Palæozoic Trap-rocks." In it he asserts that the glassy base "said to constitute a difference between the two series of rocks (Limerick and Antrim), certainly occurs in the Antrim basalts, and is common in many Carboniferous and Tertiary dolerites," and defines a *glass* base (dark under crossed prisms) as distinguished from a *felspathic* base (which exhibits double refraction). After declining to admit "that a difference in the relative proportions of any of the constituents is sufficient to indicate an essential difference in the rocks in which they occur," the author remarks in conclusion that "great differences certainly exist between augitic lavas of different volcanic districts; the same is true of those of the older geological periods; and similar differences occur between rocks of various periods. It becomes evident, therefore, that a dissimi-

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* Geol. Mag. vol. x. pp. 153–161. † Phil. Mag. vol. xxxiv. p. 336.

‡ Geol. Mag. vol. x. p. 196–8.

larity within the range of such variations can give no support to the opinion that there is an essential difference between rocks of different ages."

On June 24th of this year (1874) an important memoir was brought before the Geological Society by Mr. Allport "On the Microscopic Structure and Composition of British Carboniferous Dolerites." In the October number of the Geological Magazine is an article by Prof. Hull on the microscopic structure of the intrusive "porphyrite" (quartzless porphyritic felstone) of the Island of Lambay, and in the same magazine a supplementary note by Mr. Allport on the Phonolite from the "Wolf Rock."

Mr. Rutley, of the Geological Survey, has contributed notes upon the microscopic structure of certain trap-rocks in Somerset to the official memoir on the East-Somerset and Bristol Coal-fields, now in the press. Also in the Survey Memoir on 101 S.E. (Keswick), in the press, the author of these pages has given a detailed account, with figures, of some of the volcanic and other rocks around Keswick.

The preceding is, I believe, a fair notice of all that has been at present done in our country towards the microscopic investigation of volcanic rock-structure. Dr. Macalister, in his Presidential Address to the Royal Geological Society of Ireland, has given a summary of of work done by German petrologists in this and other branches of rock-microscopy.

The following works and papers bearing on the microscopic structure of Vesuvian lavas, have been published on the Continent.

In Zirkel's 'Mikroskopische Beschaffenheit der Mineralien und Gesteine,' 1873, and in his 'Untersuchungen über die mikroskopische Zusammensetzung der Basaltgesteine,' 1870, will be found notices of the microscopic structure of the lava-forming minerals; also in 'Mikroskopische Physiographie,' 1873, by Rosenbusch, where a list is given of the literature of rock-microscopy. Kreutz, F., "Mikrosk. Untersuchung der Vesuv-Laven vom Jahre 1868," Sitzungsberichte der k.-k. Akademie der Wissenschaften zu Wien, lix. 1869, Februar. Inostranzeff, A. von, "Ueber die Mikrostructur der Vesuv-laven vom September 1871, März und April, 1872," in Tschermak's 'Mineralogische Mittheilungen,' Wien, 1872, ii.; Neues Jahrb. 1872, 883. Fuchs, C. W. C., "Die Laven des Vesuv," Neues Jahrb. 1866, 667; 1869, 42, 169.

II. Examples of Microscopic Rock-structure among modern Lavas.

1. Trachyte, Solfatara, near Naples.

The rock first to be examined belongs to the bulky trachytic lava erupted in 1198. Scrope describes it thus *:—"A highly crystalline or granitoidal ash-grey trachyte, or rather greystone, made up of large crystals of glassy felspar imbedded in a felspathic and granular base, with a small quantity of augite."

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* Volcanos, 2nd edit. p. 321.

Microscopic examination (Plate XVII. figs. 1 & 2).—The base consists of imperfectly crystallized prisms of sanidine, with some larger ones porphyritically imbedded in it. Scattered throughout are numerous crystals of magnetite; and every here and there are others, probably both of orthoclastic felspar and augite, altered into a brown mineral showing bands parallel to the sides of the crystals. This product of alteration forms also grey and brown streaks between the small felspar prisms. In fig. 2 an irregular crystalline plate still shows some parts not wholly altered, while the compound crystal on the other side of the figure indicates the manner in which the original mineral has been replaced in regular bands parallel to the outer walls; this structure is also well seen in the oblong crystal of fig. 1 *.

With regard to the order in which crystallization has taken place, it seems certain that the magnetite was the first, the large crystals the next, and the small imperfectly formed felspar prisms the last to crystallize. In fig. 1 an example is seen of a magnetite crystal entirely surrounded by one of the brown pseudomorphs; and the way in which the minute felspar prisms have flowed round the larger crystals, invariably setting tangentially to the sides of each, is particularly well seen when viewed in polarized light, as in fig. 2. This structure of the base is especially interesting when viewed in connexion with the bulky buttress-like appearance of the lava-flow; and Scrope speaks of its remarkable mineral character as accounting "for its extremely imperfect fluidity." I shall, however, have occasion to refer again to this same plastic nature of a crystalline base when dealing with lava-flows of Lower Silurian age.

The brown pseudomorphic mineral would seem largely to consist of iron oxide; and the rock is in places reddened by it.

2. Leucitic Basalt, Torre dell' Annunziata, Naples.

The rock to which the following notes relate belongs to the Vesuvian lava-flow of 1631. Its position may be thus described:—Walking towards Naples from Torre dell' Annunziata along the seashore, the cliffs are at first seen to consist of nearly horizontal beds of somewhat coarse ash, the fragments partly rounded, while further on white lines and layers of sandy mud appear in some places. Just, however, where the railroad enters a cutting, a bed of close green-spotted lava lies upon this ash, its lower part, for about a foot or two, being very cindery and scoriaceous. It is quarried at various points along the beach, and retains the same general character as far as a large old square fort, where it is more scoriaceous. Beyond this point the upper part of the cliff-section shows loose scoriæ, and the lower part compact lava, which, however, passes in places into a sandy micaceous rock, presenting indications of partial bedding. This coast-section represents the seaward end of the lava-streams of 1631, some of which flowed for a distance of five miles.

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* It is probable that many of these pseudomorphs are after augite; but there has been so much alteration, and there are so few good crystalline forms to examine, that their nature cannot always be determined with certainty.

The lava, though often very hard and compact, is frequently full of small vesicles; the leucite crystals appear as a number of small white specks, and the augite is dark-green, while both are imbedded in a leucitic and augitic base.

Microscopic examination (Plate XVII. fig. 3).—The general appearance of this rock, when viewed in a thin slice under the microscope, is that of an open mesh-work (fig. 3), in which the meshes are formed by the transparent leucite, and the threads by minute crystals of magnetite, small prisms of triclinic felspar, and augite. A few flakes of brown magnesia-mica and some large crystals of augite are scattered about. With polarized light the leucite is black under crossed prisms, while the other ingredients, except the magnetite, show more or less of colour.

In fig. 3 the following points should be specially noted. 1. The flake of mica seems broken in two, augite now separating the two parts. 2. The magnetite grains are thickly clustered together around the mica. 3. The large crystal of augite contains several cavities filled with leucite, in one of which is a small magnetite crystal. 4. Some of the small felspar prisms shoot out into the leucite meshes.

From which one would infer:—1. That the magnetite was the first to crystallize, or was already formed when the lava was erupted. 2. Before the other minerals crystallized, the mica plate, shown in the figure, was probably cracked; and it seems likely that augite, solidifying within the crack, separated the two pieces, and caused them to push the magnetite grains in front of them *. 3. The larger augite crystals in their formation caught up some of the viscid leucite, and with it an occasional magnetite grain. 4. The leucite crystallized out, enclosing small felspar prisms and a few magnetite crystals. The crystalline form of the leucite is seldom seen to perfection, owing partly, no doubt, to the interference of the crystals one with another.

In the crystals of leucite there occur a great many stone-cavities, usually of a more or less circular form. The arrangement of these cavities is especially striking. In a very large proportion of the crystals they form a circle a short distance within the circumference, as seen in figs. 24, 26, 27 (fig. 23 *a* represents the average size of these leucite crystals). In most cases the cavities are completely crystalline and dark; but some of the larger ones are only partially so, thus forming a combined glass- and stone-cavity, as figured by Sorby in his paper on "The Structure of Crystals" (plate xviii. fig. 68) †. The same author says, "in no case have I seen decided bubbles in the cavities in leucite;" in one instance, however, I have found a bubble occupying fully one third of a compound glass- and stone-cavity, as seen in fig. 25. In another

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* Allport has found felspar crystals in the Pitchstone of Planitz, with opaque particles crowded round their sides; and he remarks, "this clearly indicates that during the formation of the crystals the matrix was in a *viscid* but not in a *fluid* state; for had the particles been quite free to move, there would have been no crowding" ("The Microscopical Examination of Rocks and Minerals," Monthly Microscopic Journal, August 1870).

† Quart. Journ. Geol. Soc. vol. xiv. p. 478.

crystal a bubble occurs independently of a cavity (fig. 30); this is either a gas-cavity, or a circular stone-cavity, with glass in the centre forming a point of light. The presence of a decided bubble within a glass- and stone-cavity is of considerable significance, because, as Sorby remarks (p. 479), "nothing but igneous fusion could so liquefy the enclosed glass that perfectly spherical bubbles could be produced."

The frequent circular arrangement of the stone-cavities, as noticed above, would seem to indicate that solidification had taken place more rapidly near the circumference of the crystal than at the centre, where such cavities are much more seldom met with *. Stone-cavities are frequently seen to be attached to acicular crystals; of this Sorby gives an example; and in all the cases I have observed the cavity is of an oval form, with its longest diameter in the direction of the length of the crystal (figs. 23 and 27), clearly showing that the original cavity was drawn out along the line of the crystal before the solidification of its contents, and whilst the surrounding leucite was in a more or less viscid state.

Figs. 23–31.—*Leucite crystals containing microlites, glass-, and stone-cavities, and magnetite grains.* Fig. 23 *a* represents the average size of these leucite crystals.

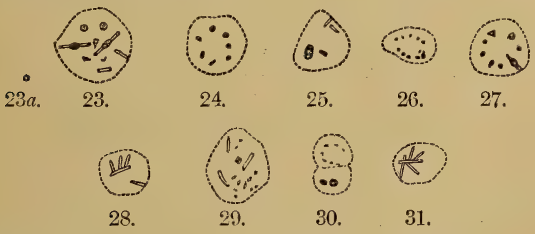


Fig. 32.—*Striated structure of leucite.* Polarized light.

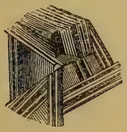
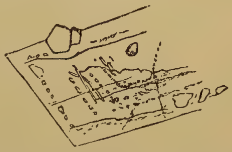


Fig. 33.—*Part of the augite crystal in fig.* 5 (Plate XVII.), more highly magnified.



Acicular crystals also frequently occur within the leucite independently of glass- or stone-cavities, as in figs. 28 and 31. In fig. 29, along with some small acicular crystals and minute stone-cavities, is a grain of magnetite; and the almost triangular dark spot in fig. 27 is probably magnetite also.

The order in which the constituent minerals of this rock seem to have crystallized out, as mentioned above, appears at first sigh

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* Cavities, whether stone, glass, or liquid, are usually more numerous the more rapid the process of solidification has been.

perhaps somewhat anomalous, since their fusibility before the blowpipe stands in the following order:—

Leucite, infusible.
Magnetite, fuses with extreme difficulty.
Magnesia-mica, difficultly fusible.
Felspar, fusible, but often with difficulty.
Augite, generally fusible.

Nevertheless it seems, from the various facts noticed in the preceding paragraphs, that the four last-named minerals were held in solution by leucite in a state of fusion; and that instead of this mineral crystallizing out first, it deposited in succession the magnetite, the mica, the felspar, and the augite, and last of all probably solidified quickly, enclosing within its crystals glass- and stone-cavities, and magnetite and felspar crystals. Sorby, in speaking of the analogy between glass-cavities and fluid-cavities, says *, " their peculiar characters can be most perfectly explained, if we suppose that the glassy base, when in a state of fusion, acted like a solvent liquid and dissolved various mineral substances, which were deposited on cooling in precisely the same manner as crystals are deposited on the cooling of a saturated aqueous solution. There is therefore, in my opinion, no more necessary connexion between the temperature at which the crystals were deposited from this glassy solvent and their own fusing-point when heated alone, than between the temperature at which crystals are deposited from solution in water and their own fusing-point, even if they be fusible. In both cases the only necessary connexion is, that the crystals could not be deposited in a *solid* form, except at a lower temperature than that at which they become *liquid*; but it might be any heat less than that high enough to cause the glassy solvent to be sufficiently fluid."

Might not the circular distribution of the stone-cavities, as noticed of such frequent occurrence in this specimen, indicate that, after the leucitic glassy solvent had deposited the other minerals, it began to crystallize at numerous points, slowly at first, thus pushing outwards and away from these centres most of the previously formed minerals, until, as the growing leucitic crystals more nearly approached each other, the solidification became more rapid, and, in consequence, more cavities and particles were enclosed near their outer boundaries than at the centre?

Zirkel describes † some leucite crystals from Capo di Bove, in which there is an outer circle of opaque grains, and an inner one of clear glass with bubbles. On p. 149 he mentions the various bodies enclosed in leucite:—little needles or grains of augite; colourless felspar microlites; roundish or egg-shaped blackish or brownish transparent grains which, for the most part, belong to a half glassy substance; pure glass-cavities; and opaque particles of magnetite. Rosenbusch ‡ mentions cases of glass-cavities in leucite with intersecting bubbles, and remarks that gas-pores are seldom found singly,

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* " Structure of Crystals," Quart. Journ. Geol. Soc. vol. xiv. p. 477.
† Mikroskopische Beschaffenheit, p. 75.
‡ Mikroskopische Physiographie, p. 192.

but generally united, like strings of beads, parallel to the crystal sides. He also describes it as specially characteristic of leucite crystals that they are surrounded outside by a close-lying tangential augite-microlitic circle.

3. Leucitic Basalt. Near Torre del Greco.

This rock, which is part of the lava-flow of 1794, exhibits a well-marked columnar structure. It is compact, contains larger leucite crystals than the last, and they are further apart, while the augite is in greater abundance, and the crystals usually larger.

The general microscopic character of this lava is shown in figs. 4 and 5, the latter representing a portion of the former more highly magnified. The light brown is augite, the highest example in the figure being a group of crystalline grains, which come out distinct from one another, in colour, under polarized light, and are represented in their natural size just below the figure. The white meshes are leucite; and the base consists of numerous magnetite crystals, acicular prisms of triclinic felspar, and a greenish and brown diffused mineral, probably in great measure a product of alteration. Every here and there larger prismatic crystals of triclinic felspar occur imbedded in the base.

The chief points to be noticed are the following:—The leucite crystals stand out more apart from each other than in the example of the 1631 lava, and have much more of the base between them. In no one instance have I observed the circular series of stone-cavities so common within the *closely crowded* crystals of the last specimen; but the crystals contain many acicular prisms and some grains of magnetite. Glass- and stone- cavities are by no means so abundant as in the former example. There are a few instances of what must be either gas- or vapour- cavities, or circular glass-cavities, converted into stone-cavities, all but the central point; in fig. 4 is one of these bubble-like bodies, within a leucite crystal, next to the augite, at the south-western corner. Many of the leucite crystals also show, under crossed prisms, the finely striated structure (fig. 32), which will be noticed again in describing the next specimen.

The augite crystals present many glass-cavities, some of which contain magnetite grains, as is the case with one in fig. 33; and others, having the crystalline form of augite, give rise to a class of *negative* crystals (fig. 5). The augite also encloses long prismatic crystals (fig. 33), and some shorter and thicker ones. In one instance a group of augite crystals seems to have been surrounded by leucite. In some cases, however, it would seem as if the augite crystals had been broken, and the leucite had crystallized around and among the broken pieces; thus, in fig. 4, the piece of augite on the western edge of the disk was probably (the whole crystal being seen) the continuation of the lower portion; but it seems to have been broken away, and the leucite to have solidified between the severed fragments. In the lower part of this same augite crystal (fig. 33) there occur a great many glass-cavities, some large and filled with leucite, but many very small, arranged frequently in lines parallel to the outer walls of the crystal; moreover the banded structure often seen in these crystals, either with or without the aid of polarized light, in this case conforms more or less to the lines of cavities; but since the banded structure seems often to be strongly developed without the presence of any *visible* lines of cavities, there *may* be no direct authority for connecting the two together. Still the very marked bands occurring in some pseudomorphs, as in figs. 1 and 2, certainly suggest a facility of access of the replacing mineral along certain lines corresponding to the original planes of growth.

4. Leucitic Basalt. Albano, near Rome.

The rock here described belongs to an old lava-flow of the Alban Mount. It is very compact, and is quarried for road-mending beside the bridge spanning a stream near Albano Railway-station, and between it and the town of Albano. The leucite crystals are generally small; and while there is more of the general base between them than is the case in the rock represented in fig. 3, there is far less than in the last-described specimen. One general character of the leucite here is its semireticulated appearance, an irregular network more or less covering the crystal-sections. In a good many cases the circular arrangement of the stone-cavities, rather near the circumference of some of the crystals, is evident, though it is perhaps not quite so general as in the 1631 lava of Vesuvius. Some of the crystals present the beautifully striated structure, in polarized light, referred to in describing the last example; but in one case, where there is a *collection* of leucite crystals, *without any intervening base*, this structure is seen to great perfection (fig. 32), different series of most beautifully parallel lines meeting one another at various angles, frequently right angles.

Zirkel remarks * that since the discovery of the tetragonal crystallization of leucite, light is thrown upon the peculiar optical relations of the mineral, which were scarcely to be explained on the former belief of its crystallizing in the cubical system. But previous to this, Biot and Des Cloiseaux had observed that leucite, under polarized light, did not behave like a crystal belonging to the "regular" system. †

In this specimen the augite is very plentiful, both in large crystals and in very small particles, helping to form the general base. Some large augite crystals have caught up the leucitic matter while this was yet in a viscid condition: and there are cases in which the leucite has most clearly formed around the previously solidified augite. As in the former examples, the augite crystals frequently contain magnetite grains.

To this general account of a few leucitic lavas I add two analyses

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* Mikroskopische Beschaffenheit, p. 152.

† Des Cloiseaux made an elaborate examination of a leucite crystal, with a view to learn something about the polarization striæ: see "Nouvelles recherches sur les propriétés optiques," &c. (Paris, 1867), pp. 3–5, Inst. Imp. de la France, tome xviii.

of similar rocks from Vesuvius, as given by Prof. Phillips in his work on that mountain, in order that they may be contrasted with analyses of much more ancient lavas from Cumberland and Wales, to be given hereafter.

	No. 1.		No. 2.
Silica	38·888		48·02
Lime	17·698		10·18
Alumina	14·127		20·78
Protoxide of iron	12·698	Protox. & Perox.	7·97
„ of manganese	0·010		. .
Magnesia	3·333		1·16
Soda	10·000		3·65
Potassa	1·190		7·12
Water	2·063		trace.
Sulphuric acid Titanic acid Copper	trace		traces of Chl. Sod. etc.

No. 1, by Prof. Sylvester, is of the 1867–68 lava, its compact part. No. 2, by Wedding, represents an earlier current. Prof. Phillips speaks of leucite thus *—"frequent in the lavas of Somma, and ejected blocks; less frequent in Vesuvian lava." It seems hard, however, to conceive of its being in greater abundance than in the examples of Vesuvian lava-flows given above; but in some cases the crystals may of course be larger, and therefore more *visible* than in others.

Summary.

1. The Trachyte (or greystone) of the Solfatara exhibits a well-marked flow in the crystalline felspathic base. In the lavas of Vesuvius and Albano the leucite seems, in part at any rate, to take the place of the felspar of other lavas; and the majority of the leucite crystals seem to be somewhat imperfectly formed, as is the case with the small felspar prisms of the Solfatara rock.
2. The order of crystallization of the minerals in the examples given is the following—magnetite, felspar in large or small *distinct* crystals, augite, felspathic or leucitic solvent.
3. Some of the crystals first formed were broken, and rendered imperfect, before the viscid state of igneous fusion ceased.
4. Even in such modern lava-flows as that of the Solfatara considerable changes have taken place, by alteration and the replacement of one mineral by another, and this very generally in successive layers corresponding to the crystal-outline.

III. EXAMPLES OF MICROSCOPIC ROCK-STRUCTURE AMONG THE LAVAS AND ASHES OF WALES.

a. *Aran and Arenig Felstones.*

Prof. Ramsay has described the rock of the Arans as much resem-

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* Vesuvius, p. 292.

bling that of Cader Idris, "being felspathic, somewhat harsh to the touch, often porphyritic, sometimes columnar"*.

The specimens which I have examined under the microscope are from the summits of Aran Benlynn and Aran Mowddwy, and their general appearance is represented in figs. 16, 17, and 18.

1. *Aran Mowddwy* (figs. 16 and 17).—In the sliced specimens of this rock, the characteristic felsitic structure is seen. Upon a white, hazy, and milky-looking ground are scattered numerous small irregularly shaped particles, some forming greenish and yellowish-green patches (fig. 16); these seem to be all products of alteration, and are quite distinct from the felsitic base. Porphyritically imbedded in the base are scattered crystals of felspar, some of which have margins apparently shading off into the milky matrix; others are distinct orthoclase twins; and there are a few instances of fragments of triclinic felspar. Under polarized light the hazy felsitic base breaks up into an irregular coloured breccia, very characteristic of this class of rocks and quite unlike any thing met with in other groups of the volcanic series (fig. 17). As the polarizer or analyzer is rotated the colours change to their complementaries; but there is nothing whatever in the felsitic base, when viewed by unpolarized light, to show where the particular outlines of the coloured parts will appear. The small particles scattered about the hazy base maintain their distinctness while the change of colour goes on around them; and the thicker green patches appear dark, for the most part, under crossed prisms. Many of the felspar crystals are much altered; but in several cases a twin structure is well seen in polarized light.

The following is an analysis† of this Aran Mowddwy felstone, beside which I will place, for comparison, Durocher's *mean* of analyses by different experimenters:—

	Aran Mowddwy.	Durocher's Mean.
Silica	83·802	75·4
Alumina	7·686	15·0
Potash	2·161	3·1
Soda	4·229	1·3
Lime	·896	·8
Magnesia	·109	1·1
Ferrous oxide	·408	2·3
Ferric oxide	·111	
Bisulphide of iron	·191	
Phosphoric acid	·089	
Sulphuric acid	·017	
Carbonic acid	trace.	
Loss on ignition	·301	1·0
	100·00	100·0

It will be seen that the percentage of silica in the analysis is unusually high, exceeding the *maximum* given by both Haughton and Durocher by 7 or 8 per cent. The percentage of alumina, on the other hand, is low, while that of soda is fairly high. There is little

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* 'The Geology of North Wales,' p. 33.

† This, together with three analyses of Cumberland rocks, given hereafter, have been made for me by Mr. John Hughes, F.C.S.

doubt that the triclinic felspar observed under the microscope is oligoclase.

2. *Aran Benlynn* (fig. 18).—In this specimen very much of the characteristic hazy structure is obscured by the presence of innumerable grains and crystals of chlorite with their characteristic vermicular form. There are many felspar crystals decomposed very much, except just round their edges, which present a clear unaltered appearance. Zirkel describes felspar crystals in porphyrite having a similar structure, being filled in part with decomposition-products and in part with foreign substances, their edge alone being clear and unchanged *.

In polarized light the chlorite shows colour where it is unaltered and crystallized. Some of the felspar is seen to be distinctly triclinic.

When the analyzer is removed and the polarizer rotated, the many chloritic grains show distinct dichroism in groups, and the heart of very many of the felspar crystals exhibits the same, as if these latter had their inner portions removed and the space filled with chlorite. Where the chloritic granules are not so thickly grouped together the base shows the same coloured-breccia structure as that of the last example, when the prisms are crossed.

3. *Y Foel-ddu.*—This compact light-coloured mass of intrusive felstone † presents the same general microscopic appearance as those just described, except that it is permeated in all directions by strings and patches of the yellowish green mineral. There are many small crystals and fragments of felspar *crystals,* some of which are certainly triclinic. Thin felsitic veins run through the base in places.

4. *Efridd Trawscoed.*—The very compact felstone of this part, the equivalent of that of the Arans, repeats in its microscopic structure the characters already given for the Aran rock. It is traversed in some parts by a very great quantity of yellowish and brown mineral in lines and patches, and in those parts examined presents fewer felspar crystals of any size.

b. *Snowdon Felstones.*

5. *Llanberis Route* (fig. 19).—The microscopic appearance of the upper part of the Snowdon felstone, on this route, is very similar indeed to that of the Aran Mowddwy rock, presenting quite the same hazy base with a plentiful sprinkling of small particles upon it, and traversed in parts by lines of yellowish and brown mineral (fig. 19). Every here and there quartz may be distinguished from the surrounding felsitic base, and more so perhaps than in the case of the Aran rock. Here also the fragments of felspar crystals consist both of orthoclase and plagioclase.

6. *Glaslyn, Snowdon.*—The top of the same felstone-bed, upon the other side of Snowdon, just above Glaslyn, where it is much cleaved, shows the same felsitic microscopic structure as on the

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* Mikroskopische Beschaffenheit, p. 404.

† Some of the published maps have been wrongly *coloured,* as if this rock were a *contemporaneous* trap, like that of Aran Benlynn and Mowddwy.

west of the Snowdon peak, though this is a good deal masked by a network of yellowish-green particles, with greenish and brown lines running in the same direction as the cleavage. In polarized light, when the prisms are crossed, the granular parts look like golden and reticulated threads running all in one direction, with here and there a crack filled with a dark brown ferruginous mineral; and between the threads are numerous drawn-out and often lenticular felsitic spaces showing the characteristic coloured-breccia structure. The general veined and reticulated appearance, however, is best seen when, the analyzer being removed, a plate of selenite is placed behind the slide and the polarizer is rotated. Under these conditions the granular mineral shows itself strongly dichroic, the same colour prevailing at once over the greater part of the field of view, the complementary appearing amongst it, but not so prominently. Thus, in one position of the prism the reticulated veins may appear mostly red, with scattered green spots and lines, in another position mainly green; in both cases the felsitic base forming the meshes is white and clear.

When carefully examined, it is plain that, in all the examples of felstone above described, the little particles and granules scattered over the felsitic base are of the same mineral, presenting more or less distinct dichroism; and in this case of a cleaved felstone they have been collected together along lines, and hence a more marked dichroic effect is produced. I think, also, that there is little doubt that the mineral is chlorite, seldom occurring crystallized, and often being itself partly altered*. Before referring to the structure of some of the slaggy felstones of Snowdon, it will be as well to describe that of the felstone lying below the intrusive greenstone of Craig Wen, near Capel Curig, since in some points it closely resembles the cleaved Glaslyn rock.

7. *South of Llyn Cwlyd* (*Capel Curig*).—The rock under description is the lowest of the thin felstone beds just south of Llyn Cwlyd. Its structure is very similar to the last, only that the dichroic granules are even more numerous, and the felsitic base appears only at intervals. There are small fragments of felspar crystals disseminated throughout. The dichroism is as in the last example, but not along lines, except in some parts, where there seems to be a tendency to this veined structure.

8. *Llanberis Route, Snowdon,* Slaggy Felstone (fig. 20).—The general character of the *lower* part of the Snowdon Felstones is represented in fig. 20. There is the same hazy and milky-looking ground characteristic of the previously described felstones; but the scattered particles, many of which are slightly dichroic, are numerous, and there is a great deal of the greenish mineral, forming bands and streaks which frequently curve round the felspar fragments. These last consist both of orthoclase and plagioclase; the

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* The brown colour so frequently occurring with the green is probably due to peroxidation of the iron protoxide; or some of the green mineral may be delessite or chlorophæite, which contain a larger amount of iron, and become brown on exposure. The dichroism in the above case is generally well marked, though faint, when the selenite is *not* used.

large fragment in the figure shows the coloured bands in polarized light characteristic of the triclinic felspars. From the position of this and other fragments, with their long axis at right angles to the direction of the streaks, it seems probable that the state of fluidity could not have been very great, or they would have been turned round with the flow and made to lie with their longer diameters in the direction of the bands.

When viewed with a $\frac{1}{4}$-inch objective, the green bands are seen to consist of an aggregation of the small light-green particles, scattered over the clearer part of the base, and every here and there along the bands the dichroism is decided, though partial at other spots. In polarized light, the Nicols being crossed, the felsitic base shows the usual coloured-breccia structure along lines separated by darker bands and streaks of the green mineral, which certainly seems to be chlorite. If chlorite, however, be in all cases a secondary product, then the streaky character of the rock may be due, not to its original flow as a lava, but to subsequent metamorphism; and the strong likeness between this and similar-looking rocks in Cumberland (fig. 11), which I cannot but regard as highly altered ash, seems to render it possible that the Snowdon rock is also much metamorphosed.

Another specimen, showing a number of fine contorted lines very like those of bedding, reveals very little indication of a banded structure, similar to the last, when cut at right angles to these lines. It presents, however, in a most decided manner, the hazy structure as shown in fig. 16, with numerous light-green particles scattered about and sometimes collected into groups and lines. Many of these particles are decidedly dichroic. In polarized light, the characteristic felsitic reaction is clear, and the only felspar crystals or fragments of such to be seen in the slice are triclinic.

c. *Ashes of Snowdon, Arenig, and the Arans.*

1. *Glaslyn, Snowdon.*—The specimens examined were taken from near the faulted junction of ash and felstone just above and north of Glaslyn. The ash presents a beautiful, finely bedded appearance outside, but has been altered into a compact, blue, felstone-like rock, just similar to the altered ashes around parts of Scawfell in Cumberland.

Viewed with a $\frac{1}{4}$-inch objective, the structure is seen to be very similar to that shown in fig. 14, from Great Gable, Cumberland, and fig. 16, from Aran Mowddwy—the former being a bedded, highly altered, fine ash, and the latter a compact felstone. Upon the hazy base are scattered many particles of the green dichroic mineral, which are gathered together in groups in some parts, and fill cracks in others. There are no distinct crystals or even fragments of crystals of felspar in this case. With crossed Nicols the coloured-breccia felsitic structure is clearly shown, as in fig. 21—the green mineral, where its particles are closely aggregated, presenting a dark appearance. As far as microscopic structure goes, there is *no* difference between this specimen and the last, or the felstone of Aran Mowddwy.

2. *The Arans.*—The ashes lying below the felstones of Aran Benlynn are very unmistakable and quite similar to the coarse and bedded ashes of Cumberland. In the specimen now to be described, the fragments, which are small, are clearly discernible upon the smooth surface from which the slice has been cut, and the rock presents a mottled and somewhat felstone-like appearance. Its microscopic structure is shown in fig. 22. One of the fragments in the slice is of trap, with acicular prisms and triclinic felspar; but most of them seem to be of felstone containing entire or fragmentary crystals of felspar, several of which are triclinic. In the *fine* part represented in the figure, many broken crystals are scattered in a hazy base, which presents the felsitic reaction under crossed Nicols.

In some parts north of Aran Benlynn, and again at the top of Aran Mowddwy, there occur, within the mass of the felstone, brecciated and ashy parts. Such intercalated ashes are much altered, and frequently reveal their structure only by weathering on the outside. A slice of a well-bedded but highly altered *fine* ash on the top of Aran Mowddwy, presents, in *every respect*, a similar appearance under the microscope to the neighbouring felstone, as shown in fig. 16, except that in the fine ash there are no crystals of felspar or large fragments of such crystals.

3. *The Arenigs.*—In some parts of the ash on Y Wenalt, south of Efridd Trawscoed, there are short irreguular black lines, giving very much the appearance of a viscous flow. A microscopic section of such a rock reveals clearly that there has been more or less of a flow around the small and larger fragments of which the ash is made up.

This structure, in the present instance, seems as if it might well be due to subsequent alteration of the beds; for northwards, where they very much thicken out, they are altered into a compact felstone-like rock, with fragments barely or not at all discernible, except frequently on the outside of weathered masses. Prof. Ramsay thus describes them around Llyn Arenig:—"They are thick-bedded, and frequently porphyritic, but so massive, and they so much resemble some of the true felstone porphyries, that the observer is apt to doubt of their truly stratified character, especially as it frequently happens that they are so much jointed that in places they look almost columnar. Still, when viewed in favouring lights on a large scale, the long lines of massive beds that streak the steep flanks of the hills generally become sufficiently apparent; and when traced along the strike to Mynydd Nodol and Arenig-bach, all doubt ceases; for, by degrees becoming less jointed and massive, their true-bedded structure comes out with perfect distinctness"*.

When such rocks as these are viewed in thin slices under the microscope, it is only possible on some few parts to detect any of the outlines of the original fragments, the general appearance being that so characteristic of the undoubted felstones. Care, of course, is taken to select specimens which seem from their weathered exterior to be made up of comparatively small fragments, so that several or many may come into one field of view.

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* "The Geology of North Wales," Mem. Geol. Survey, vol. iii. p. 50.

Summary.

1. Specimens of trap collected from the Arans, the Arenigs, and Snowdon and its neighbourhood, all have the same microscopic structure.

2. This structure presents a hazy or milky-looking base with scattered particles of a light-green or brownish dichroic mineral (chlorite or its allies), and generally some porphyritically imbedded felspar crystals, or fragments of such, both orthoclase and plagioclase (probably oligoclase). In polarized light, on crossing the Nicols, the base breaks up into an irregular coloured breccia, the colours changing to their complementaries on rotating either of the prisms.

3. Finely bedded ash, when *highly altered*, is undistinguishable in microscopic structure from an undoubted felstone-lava.

4. Ash of a coarser nature, when highly altered, is also very generally not to be distinguished microscopically from felstone, though now and then the outlines of some of the fragments will reveal its true nature. Metamorphism has sometimes given rise to a kind of viscous flow of chloritic matter round the larger fragments.

5. The fragments which make up the coarser ash-rocks seem generally to consist of felstone containing both orthoclase and plagioclase crystals or fragments; but occasionally there occur pieces of a more crystalline nature, with minute acicular prisms and plagioclase felspar.

6. In many cases the only tests that can be applied to distinguish between highly altered ash-rock and felstone are, the presence of a bedded or fragmentary appearance on *weathered* surfaces, and the gradual passage into less-altered and unmistakable ash.

IV. EXAMPLES OF MICROSCOPIC ROCK-STRUCTURE AMONG THE LAVAS AND ASHES OF CUMBERLAND.

The following notes will afford only such a preliminary sketch of these rocks as will suffice for a general comparison with those just treated of. All details, and most of the conclusions arrived at from a study of the Cumberland volcanic series in the field, during several past years, have been necessarily reserved for the Survey Memoir upon 101 S.E., now in the press. The Volcanic Series of Borrowdale (green slates and porphyries) consists of alternations of contemporaneous traps (lava-beds), ash, and breccia, with a thickness of many thousand feet, and without any intercalations of *ordinary* sedimentary material except *quite* at the base. Only within the last two years has the microscopic examination of these rocks led me to recognize any decided difference between the lavas of Cumberland and those of Wales. I had, however, previous to the use of the microscope, separated a well-marked series of undoubtedly contemporaneous traps, from another great series of felstone-like rocks which, *from evidence in the field*, I was led to believe were only highly altered ash-beds. Microscopic study, I think, goes a long way towards confirming this conclusion.

Three specimens of lavas, from widely separated parts of the district, shall now be described in general terms, as representative samples of a considerable number of specimens which have been examined and which will be treated of fully elsewhere.

a. *Cumberland Lavas.*

The contemporaneous traps of the Borrowdale volcanic series may with as much reason be called *lavas* as any of the modern flows of Vesuvius. The thickness of the *separate* flows is in general not great; their upper and lower surfaces are very usually slaggy and scoriaceous; and in many cases the vesicles, where they occur, are drawn out in the direction of flow. I have seen some of these old traps presenting an outward appearance almost exactly similar to that of many a bed of lava round Vesuvius. Their thickness is, as one would expect, subject to very sudden and wide variations; yet many beds may be traced along their present outcrop for a distance of several miles.

1. *Eycott Hill* (Porphyritic Dolerite, Plate XVII. fig. 6).—This rock is one of a thick series of lava-beds with vesicular portions, occurring separated from the main mass of the Borrowdale Series at the north-east corner of the district. Its lithological structure is that of a compact base containing dark-green or black spots of a soft mineral, and large felspar crystals, many of them an inch long.

In fig. 6 the general microscopic structure of this rock is seen, with the exception of the large felspar crystals. The base consists of a network of acicular felspar prisms, the intervals being filled up with a dirty green and brown pseudomorphic mineral, and numerous crystals of magnetite. The large felspar crystals are triclinic, contain glass-cavities and grains of magnetite, and are much cracked. Augite, in crystals and grains, is interspersed with the other minerals; much of it is in the form of pseudomorphs (the soft dark spots before spoken of); but there are some unaltered twin crystals of considerable size. A portion of one of these is shown in the figure; and in polarized light the parts on either side of the faint median horizontal line show different colours, thus revealing the twin structure. The same crystal contains several glass-cavities, in one of which are included two small magnetite crystals and a bubble (see figure, close to a crack). Some small parts of the crystal are replaced by a green mineral showing a faint dichroism, and which is probably chlorite. The many green pseudomorphs scattered about are also slightly dichroic, as well as parts of the dirty-green base; it is therefore probable that in great part the pseudomorphic mineral is chlorite or one of its allies, which may be partly altered, forming the browner part of the base*. Some of the green pseudomorphs have the appearance of being after olivine; and as that mineral has been found in some of these rocks, its occurrence here is not at all unlikely.

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* This rock, in so far as it resembles an altered dolerite, might be called a diabase. With regard to the greenish mineral, Zirkel remarks, under the head of Diabase (Mikroskopische Beschaffenheit, p. 407), that it seems to be chlorite and probably a decomposition-product of augite.

If the figures 5 and 6 be compared, it will be seen that the structure of the base is very similar in the two cases. In the Torre-del-Greco lava (fig. 5) some of the more transparent green parts of the base are faintly dichroic, as in the old Cumberland trap. In the former, however, leucite occurs filling up the interstices, which appear dark under crossed prisms; while in the latter there is no absolute darkness when the Nicols are crossed, since the felspar, which seems here to take the place of the leucite, remains more or less transparent, and the dirty green matter, where thickest, is only partially dark.

2. *Brown Knotts*, West of Bleaberry Fell, near Keswick (fig. 7).—This is but one of a series of lava-beds cropping out along the hillside between the eastern edge of Derwentwater and the summit of Bleaberry Fell, and which will be found all fully described in the Survey Memoir. It is the basement-bed of a succession of flows forming Brown Knotts. The flow itself probably averages not more than 15 feet in thickness, rests upon partially altered and false-bedded ash, and presents a very slaggy-looking and vesicular top. The heart of the rock is very compact, fine-grained, of a grey-blue colour, showing a few very small, soft, black spots, and some very minute felspar crystals, with an occasional brick-red, earthy spot here and there. It breaks up very much along numerous weathered joint-lines, and altogether presents an excellent example of an ancient lava.

Examined microscopically, the general structure is that shown in fig. 7. The base consists of numberless acicular felspar prisms and magnetite crystals, between which is an abundant development of yellowish-green and brownish mineral, scarcely if at all dichroic. Within the base are scattered small crystals of plagioclase and orthoclase felspar, singly and in groups; one of the latter is seen in the figure. Very little unaltered augite is apparent. Every here and there are vesicles filled with calcite and green earth, presenting the appearance, under crossed Nicols, of dark irregularly shaped spots, surrounded by a coloured edging. Much of the diffused mineral of the base may not unlikely be pseudomorphic matter after augite. There are a few clear green pseudomorphs (a part of one is seen in the figure) which show a faint dichroism and are very likely chlorite replacing other minerals. Zirkel remarks of chlorite*, "on account of its optically uniaxal character, a horizontally cleaved chlorite plate can develop no dichroism; but chlorite plates cut obliquely or even at right angles to the basal plane, when tested with a single Nicol, exhibit somewhat feeble dichroism, giving rise to only a little change from clear to dark tints of green."

When the Nicols are crossed, the base presents the same general appearance as in the last example, only that the diffused mineral seems on the whole somewhat darker.

The following is an analysis of this rock; and beside it I place that of another lava-bed from the same hill, presenting *lithologically*

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* Mikroskopische Beschaffenheit, p. 190.

a somewhat different appearance, though the chemical composition of the two appears pretty similar*.

	Brown Knotts.	Iron Crag.
Silica	60·718	59·511
Alumina	14·894	17·460
Potash	2·354	3·705
Soda	2·843	3·093
Lime	6·048	5·376
Magnesia	1·909	1·801
Ferrous oxide	6·426	4·926
Ferric oxide	1·405	1·271
Bisulphide of iron	·395	·604
Phosphoric acid	·281	·115
Sulphuric acid	·103	·086
Carbonic acid	1·660	1·569
Loss on ignition	·964	·483
	100·000	100·000

3. *Latterbarrow*, near the foot of Wastwater (fig. 8).—The rock now to be described occurs near syenite and granite, and among highly altered ashes penetrated by veins of felstone from the neighbouring syenite. Its lithological structure is that of a dark-grey base with imbedded white felspar crystals and some soft green spots.

When viewed microscopically, the structure is found to be somewhat variable. In many parts there is a decided network of acicular felspar prisms, but in other parts only a number of greenish particles with patches of green mineral on a white hazy ground. There is sometimes a distinct flow of the small crystalline needles around the large crystals of felspar and altered augite, as seen in fig. 8, with crossed Nicols; in this figure there occur portions of two large highly altered felspar crystals and some smaller fragments, together with what appears like a pseudomorph after augite with its angles much rounded. The base is not absolutely dark when thus viewed under crossed prisms; for when a ¼-inch objective is used, there are seen to occur, between the dark parts formed by a diffused altered mineral, numerous interspaces with a felsitic structure. Those parts in which the acicular network is absent, show, under crossed Nicols, the coloured-breccia reaction of a felsitic base.

The felspar is throughout very much altered, and its species not easy of determination; some of it, however, is certainly orthoclase, one example showing its characteristic twin structure. The grains of magnetite are few; and only a little of the augite remains unchanged.

General Remarks.—The preceding examples serve to show the general character of these old contemporaneous traps. Many others have of course been examined in the same way, and the general re-

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* I have little doubt that there are some few examples among the contemporaneous traps which more nearly approach true basalts than these, the analysis of which would probably be of a more basic character; but the above are characteristic samples of the group as a whole.

sult is as follows. Some have a decidedly crystalline structure, with oftentimes a distinct flow of the small crystalline needles around the larger crystals, and contain both triclinic and monoclinic felspar, magnetite, and augite in greater or less abundance, with perhaps some pseudomorphs after olivine. Others have the acicular structure almost but seldom quite lost, and exhibit for the most part a felsitic base, in which the same minerals as before are scattered in varying quantity, together, very frequently, with garnets. These more felsitic-looking traps occasionally contain a large quantity of augite, sometimes in good twins.

At first I was inclined to think that the more felsitic examples might be due to an alteration of originally more crystalline beds; but since they are sometimes found to alternate with the latter upon the same hill-side, perhaps the more truthful supposition would be that the separate flows were often of somewhat varying nature. Of the analyses given above, the one (Brown Knotts) represents a highly crystalline example, and the other (Iron Crag) a rock of the more felsitic-looking class.

b. *Cumberland Ashes and Felstone-like rocks.*

The ejected material associated with the old lavas presents great variety in the size of the component fragments, and in the degree of alteration to which it has been since subjected.

1. *Typical Ash, Steel Fell.*—Fig. 10 is an example from a slice of well-bedded ash-rock, seen under polarized light with the Nicols crossed. The dark part consists of very fine matter, and the fragments are mostly felsitic, lying with their long axes parallel with the planes of bedding. Among the fragments, crystals of felspar and green pseudomorphs after augite are not unfrequent, some of them quite as perfect as many crystals in the traps.

2. *Altered Slate, Capel Curig.*—In order that correct conclusions might be drawn with regard to the structure of these altered ashes, I have, for comparison, examined the slate immediately beneath the intrusive greenstone sheet of Craig Wen, near Capel Curig. It has been altered into an exceedingly compact, almost felsitic-looking rock, weathering white along the edges, like felstone. When viewed with a high power it is found to consist of very minute granules, with darker patches here and there, made up of the same, very closely aggregated. Under polarized light, with the prisms crossed, the ground is dark, with scattered points of light, caused by the intermixture of doubly refracting particles.

Now the very finely granular part of the ash represented in fig. 10, has precisely the same *structure* as the fine altered sedimentary rock. If then we find other rocks in this ashy series looking compact and felstone-like, yet having the same minute granular structure as is common to the altered slate of Craig Wen and the recognizable fine ash, we are surely entitled to conclude that the rocks in question consist of exceedingly fine ashy or other matter, and are not true lava-beds.

3. *Bleaberry Fell.*—The example I will first take of these doubtful-looking rocks is from the summit of Bleaberry Fell, near Keswick,

where much of the felspathic ash is a good deal altered. In appearance, the rock under examination is mottled, of a light blue or greyish colour, and very similar to parts of the Lower Aran Ash already described (fig. 22). Its general microscopic structure is represented in fig. 9, where an attempt is made to show the minutely granular character of the base, precisely similar to that of the two test-specimens already described. There are many fragments of felspar crystals scattered about, and one or two tolerably perfect, such as the orthoclase twin shown in the figure. Both plagioclase and orthoclase occur, very highly altered, and frequently more so within their interior than round their edges. There is a good deal of chlorite, which shows its dichroism very markedly in some cases, and occurs disseminated throughout the base and filling cracks and cavities. Some of the green pseudomorphs may be after augite; but there is none of the unaltered mineral left, nor are there present any acicular crystals or magnetite grains. From the above description it will be evident that this rock presents very decided differences from the undoubted lavas of the district: *more* approximates to the Welsh felstones; but most resembles in its structure the test-specimen of ash already described. When the slide represented in fig. 9 is viewed with polarized light, under crossed prisms, the appearance is similar to that shown in fig. 10—altered felspar crystals and fragments on a dark ground with scattered points of light.

4. *Hart Side, north of Glencoindale Head.*—This example is one of a coarse ash. It has the same general mottled felsitic appearance as the last, but on the weathered exterior and upon a smoothly cut surface the separate fragments are clearly discernible. The base, between the fragments, is made up of minute particles, as in the former examples; but in this case there would seem to have been a decided flow of the granular matrix around the imbedded pieces (fig. 13). The question arises, when did this flow take place? Now along the lines of flow, scattered throughout the base, and closely surrounding many of the fragments, occurs a considerable quantity of chloritic matter. This is probably a product of alteration; the way in which it has taken the place of many minerals throughout both these and the trap rocks, and the manner in which it sometimes occurs close round the edges of fragments in the ashes, suggest that it has been formed within the rocks perhaps long after their origination. Its occurrence in these flowing lines in a rock which has evidently undergone a large amount of alteration—an alteration which has been sufficient to weld together fragments of considerable size so as to be undistinguishable from each other on a newly fractured surface—would seem to point to the conclnsion that the lines of flow were produced in that very process of alteration; and I do not think that any other conclusion can, with equal probability, be arrived at.

Among the felsitic fragments there occur some tolerably perfect twin crystals of orthoclase. In a few places, where the granules in the base are not so thickly crowded together, there is, under crossed prisms, more or less of the coloured-breccia reaction characteristic of felstones.

5. *Base Brown, Borrowdale.*—The rock, the microscopic structure of which is shown in figs. 11 and 12, is exceedingly compact and felstone-like, and characterized by streaky lines resembling those in some of the felstones of Snowdon (fig. 20). Every here and there a fragment can be discerned, with the streaky lines of flow enveloping it.

Under a high power the base is as clearly granular (fig. 11) as in the test-specimen of ash (fig. 10); and in polarized light, with crossed prisms (fig. 12), it is dark, with scattered faint points of light, the broken fragments of altered felspar crystals and of felsite standing out clearly just as in fig. 10. There is here, as in the last specimen, the same collection of chloritic matter along lines of flow (fig. 11), and in some cases the chlorite would seem to have crystallized along bands in its frequent comb-like fashion. The streaky character of this rock is shown in fig. 11, and is slightly seen also in fig. 12. The structure may well be compared to that of the slaggy felstone of Snowdon (fig. 20); but there is an absence of the bands showing a felsitic structure, the base being all very closely granular.

The following is an analysis of this rock, beside which I will place, for comparison, that of the Aran Mowddwy felstone, already given.

	Base Brown.	Aran Mowddwy.
Silica	69·673	83·802
Alumina	14·492	7·686
Potash	4·554	2·161
Soda	3·017	4·229
Lime	2·296	·896
Magnesia	·324	·109
Ferrous oxide	2·784	·408
Ferric oxide	·442	·111
Bisulphide of iron	·410	·191
Phosphoric acid	·343	·089
Sulphuric acid	·205	·017
Carbonic acid	·660	trace
Loss on ignition	·800	·301
	100·000	100·000

When the analysis of this altered and felstone-like rock is compared with those of the lavas given on page 408, it will be seen that the difference chiefly consists in an increased percentage of silica, and decrease in that of lime, magnesia, and the iron oxides, while the difference between it and the Aran Mowddwy felstone is much more marked in several particulars. If I am right in believing that this rock is really but an intensely altered fine ash, it would be only reasonable to conclude that the composition would approximate to that of the lava-beds, with such differences as might result from a slightly different period of eruption* or from local circumstances.

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* The rock in question is considerably *higher* in the series than the lava-beds of which the analyses are given.

6. *Great Gable, Wastdale-Head.*—This example is one of a very highly altered, finely bedded ash, the bedding being plainly visible on the weathered face of the cliff, but the rock in its interior presenting an exceedingly compact, blue, felstone-like appearance.

Figure 14 gives the structure as seen with a high power—a very finely granular base, with numerous disseminated grains of chlorite and patches of closely aggregated particles. Were it not for the chloritic grains and some few scattered broken crystals, there would be nothing whatever to distinguish this base from the altered slate of Craig Wen. Under crossed Nicols, the ground is dark, with bright, coloured, spangled points of light, due partly to the chlorite. Besides some broken acicular crystals, such as that in the figure, there seem to be some grains of augite (?) partially altered. In *parts* of the base, where the granules are not so thickly scattered, it presents a hazy felstone-like appearance, and with crossed prisms shows the felsitic reaction.

7. *Rigghause End, Vale of St. John.*—The last of this series now to be described is a very compact rock, weathering exceedingly like some of the Welsh felstones, but passing almost imperceptibly into clearly marked felspathic ashes.

Figure 16, illustrating the structure of the Aran Mowddwy felstone, perfectly illustrates that of this rock also. The base consists of patches and particles of chlorite on a hazy white ground, a compound of quartz and felspar. Under crossed Nicols the coloured-breccia reaction is very well marked, as shown in fig. 15. There are a few fragments of felspar, some triclinic.

c. *Manner of metamorphism.*—In all these examples of altered ash, while their appearance in hand-specimens is often extremely like that of felstones, their general aspect and deportment in the field is such as led me, previous to any microscopic examination, to map them as altered beds of fragmentary material. Either traces of fragments or bedding are everywhere discernible, or the rocks pass gradually into less and less altered and unmistakable ash. The fullest development of these, at first sight, somewhat puzzling beds, is in the district north of and around Scawfell; in fact they increase in extent as the great tract of Eskdale granite is approached. Now it is clear that some kind of alteration might be expected all around the granitic centres of Eskdale, Wastdale, and Ennerdale; and since the rocks immediately surrounding these deeply formed igneous masses are for the most part composed of felspathic ashes, it is not surprising to find that they have become altered into rocks much resembling true felstones. Sorby has shown (Brit. Assoc. Rep. 1857, p. 92) that the material of both quartz and mica might be derived from felspar; so that felstone (a mixture of felspar and quartz) may well be formed by the metamorphism of felspathic ashes. At any rate it seems probable that the alteration has, in many cases, been sufficient to cause the development of a great quantity of granular chloritic matter, often flowing around the larger fragments, giving rise to the streaky appearance so similar to that of the slaggy felstones of Wales. Nor need we suppose that the ash-rocks were in any sense rendered *fluid*, in order to produce this streaky structure; for it is evident that in the case of the old lava of Snowdon (fig. 20), the flowing matter could only have been slightly viscous, or otherwise such fragments as the large one represented in the figure would have been moved round so that their longer axes would lie in the direction of the bands, instead of these last curving round them as they do.

In some places the original lines of bedding are apparent, as well as the streaky structure; and in such cases it is usual to find that the two agree in direction, as if the alteration had taken place more readily along such planes than along any others. I am therefore led to conclude that in all probability there are no contemporaneous *felstones*, answering to those of Wales, in the Cumberland district, but that the felstone-like rocks, which present none of the characters of the Cumberland traps already described as such, are the result of metamorphism taking place when buried deeply beneath overlying rocks, since removed by denudation, just as the chiastolite slate and spotted schist, surrounding the Skiddaw granite, are the results of a similar metamorphism, probably effected at the same period*.

d. *Period of metamorphism.*—It seems probable that the period during which this metamorphism chiefly took place was that of the close of the Upper Silurian or earlier part of the Old Red, and for these reasons:—1. The Upper Old Red or basement-beds of the Carboniferous series (conglomerate of Mell Fell and Pooley Bridge) rest unconformably on both Skiddaw slates and the Volcanic series. 2. Therefore the Volcanic series had been denuded from the present northern area of Skiddaw slate previous to the deposition of this conglomerate. 3. The Upper Silurians in all probability once extended over the Volcanic series before these last were denuded. 4. Mr. Aveline estimates the Upper Silurian in the Kendal district as at least 14,000 feet thick; so that at the close of this period the volcanic rocks were probably buried at a very great depth, the granite being partly formed or intruded amongst them. 5. During the whole of the Old Red period this district was being slowly raised, and denuded by the sea and atmospheric powers; and this is very likely the reason why the Old Red is here unrepresented by deposits except quite at its close or at the commencement of the Carboniferous. It would be an interesting thing to investigate this subject further, by a thorough examination of the evidence afforded by the comparative size of the liquid-cavities and their vacuities in the quartz of the granites, in the manner Mr. Sorby has so ably done in other cases; and when we consider his results, viz. "that the fluid-cavities indicate that all the elvans and granites hitherto examined were consolidated under pressures varying from about 18,000 to 78,000 feet

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* There is, however, a true felstone bed, showing lines of viscous flow, in connexion with the Coniston Limestone, west of Shap; and the difference between this and most of the altered rocks described above is very marked, both lithologically and microscopically.

of rock"*, we might rather suspect that the thickness of the overlying Upper Silurians must have been greater than the estimate above given, supposing Sorby's general inference to hold good. I should like to be able to take up this branch of the subject at some future time, unless some more competent hands would undertake it†.

e. *Parallel Metamorphism of Welsh Lavas and Ashes.*—If I am right in regarding the formation of the *felstone*-like beds in the Lake district as a result of metamorphism of felspathic ashes, it seems only reasonable to conclude that similar effects in Wales have been produced by a like process. And when one considers the clear geological evidence which Prof. Ramsay has brought forward to show that, 1, the Lower Silurian rocks were contorted and cleaved, and therefore altered, before the deposition of the Upper Silurian, and, 2, that when covered by a great thickness of Upper Silurian beds, they experienced another great disturbance, we may well conclude that the old felspathic ashes and traps must have undergone great alteration.

Prof. Ramsay has most clearly demonstrated that the felstone sheets of the Arans and of Snowdon are contemporaneous, *i. e.* that they represent old lava-flows. The nearest modern representatives of these old flows are doubtless the trachytes; thus Durocher gives the following as the means of analyses by different experimenters.

	Trachyte.	Felstone.
Silica	72·8	75·4
Alumina	15·3	15·0
Potash	6·4	3·1
Soda	1·4	1·3
Lime	0·7	0·8
Magnesia	0·9	1·1
Oxides of Iron and Manganese	1·7	2·3
Loss by ignition	0·8	1·0
	100·0	100·0

Are we not justified, then, in supposing that these old felstones had once the characters of modern trachytes‡, and that they have undergone great changes when deeply buried and subsequently, giving them their present aspect? Every year the doctrine of uniformity in the operations of nature, as advocated by Lyell, becomes stronger. Basaltic rocks are now no longer regarded (thanks in great part to the labours of Allport) as never older than

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* "Structure of Crystals," Quart. Journ. Geol. Soc. vol. xiv. p. 494.

† Since this paper was *read*, I have made a preliminary examination on this subject; and the results have been submitted to the Society. Prof. Geikie (Trans. Edin. Geol. Soc. vol. ii. pt. 3, 1874) believes that the metamorphism of the Lower Silurian rocks of the Highlands could not have taken place beneath more than 5000 feet of Upper Silurian strata. He thus differs entirely from Mr. Sorby, who believed the fluid-cavities to indicate the *consolidation* of the Highland granites under a *pressure* equivalent to that of 76,000 feet of rock.

‡ Probably rather of the group of *quartz*-trachytes than of that of the less silicated.

Tertiary (Cotta); and, as I have endeavoured to show in the course of this paper, ancient lavas having at any rate a basaltic *likeness* occur low down in the Lower Silurian Series. And if this be the case, how can we refuse to believe that trachytic lava-flows likewise occurred, similar in all essential respects to those of more modern times? We are certainly here met by a difficulty. Some modern lava-flows, such as those of Vesuvius and the older ones of the Alban Mount, are characteristically leucitic. Cotta observes, "it certainly is somewhat remarkable that hitherto no ancient leucite rock has been found," and the occurrence of leucite changed into orthoclase on the ridge of the Erzgebirge "suggests the question whether the felspar of many older rocks may not originally have been leucite whose form has become indistinct or entirely altered, so as to be no longer recognized"*. Future investigations may tend to confirm this suggestion; but at any rate Wales, with its highly siliceous class of lavas, is not likely to furnish the examples.

We have seen that it is probable that the metamorphism of the volcanic rocks in the Lake-district took place during Old Red times, and most likely during the earlier part of that period; and it is certainly a fact not a little suggestive, that as in the Lake-district, so in North Wales, there is very little Old Red, excepting *upper* beds immediately beneath and conformable to the Carboniferous Limestone. Was not the same work of upheaval and denudation of the Silurian rocks as a whole going on in the two districts at the same time? and if so, may not the period during which the extreme metamorphism of the volcanic rocks was taking place have been the same in both districts? viz. when they were buried beneath the maximum thickness of Upper Silurian rocks, and when the slow upheaval of the ancient Upper Silurian sea-bed first commenced, or, in other words, during the earlier part of the Old Red continental period (Ramsay), in the course of which volcanic activity prevailed in Scotland†, Ireland, and South-western England (Middle and Upper Devonian).

f. *Classification of Cumberland Lavas.*—In making a general comparison between the Lake-district lavas and some of those of Wales and Italy, the following points may be noted:—

1. The order in which the minerals have crystallized out is the same in the examples given, both from Italy and Cumberland—this order being, first the magnetite, next the felspar and augite, and lastly the small acicular felspar crystals and the felspathic or leucitic base.

2. In many of the Cumberland lavas there has been a distinct flow of the smaller crystals round the larger since the latter were formed, as in the case of the trachyte from the Solfatara.

3. In the Cumberland lavas the felspar in the base seems to occupy the same position as the leucite among Vesuvian lavas; compare figures 5 and 6.

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* 'Rocks Classified and Described,' English translation, p. 143.

† See Paper by Mr. Judd "On the Ancient Volcanoes of the Highlands," &c. Quart. Journ. Geol. Soc. vol. xxx. p. 220.

4. Some of the Cumberland lavas, in proportion as they lose the acicular crystalline structure, acquire a likeness in some degree to the Welsh felstones, in the general character of the base.

5. In *lithological* structure, the Cumberland lavas have, for the *most part*, much more of a felsitic than a basaltic appearance.

6. In petrological structure they have much the general character of the modern Vesuvian lavas, the separate *flows* being usually of no great thickness, being slaggy, vesicular or brecciated at top and bottom, and having often a considerable range, as if they had flowed in some cases for several miles from their point of eruption*.

In addition to these varied points of likeness and unlikeness, this further fact should be considered, that the Cumberland rocks are on the whole very different in microscopic structure and appearance from such old basalts as those of S. Staffordshire and some of those of Carboniferous age in Scotland. The reason of this *may* be, that, their age being so great, their original structure has in great part been obliterated.

In what group, then, are we to place these old Cumbrian lavas? In external appearance they are felsitic, though somewhat different in many cases from the Welsh felstones. In internal structure they have considerable analogy with the basalts, though one would often rather hesitate to call them true basalts or dolerites. In chemical composition they are neither true basalts nor true felstones. Certainly they seem to hold an intermediate position, somewhat similar to that of the trachy-dolerite group or *greystones* of Scrope. In composition they agree with porphyrite and melaphyre, as may be seen by glancing at the table of rock-analyses (p. 417). Porphyrite, however, if we accept that of Ilfield (Streng's melaphyre-porphyry) as a sample, has a different microscopic character from the Cumberland lavas; for Rose found that "thin polished plates showed a transparent matrix marked with black spots and streaks, and filled with black grains of irregular shape"†. Cotta, however, concludes (p. 166):—"According to the known analyses, both microscopic and chemical, the matrix most probably consists of an intimately blended crystalline compound of oligoclase with augite or hornblende, magnetic iron-ore, and some apatite; the fine acicular crystals appear to be augite transformed into schillerspar;" this seems *somewhat* more nearly to apply to the rocks in question. Zirkel's description of porphyrite, however, seems quite inapplicable‡.

The term melaphyre has been applied to so many different rocks that it can only be used in a general way as denoting a rock of uncertain place; and in that sense only can the lavas in question be called melaphyres.

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* Details of volcanic centres in the district, and of the old volcanic phenomena in general, will be found in the Survey Memoir on 101 S.E., now in the press.

† Rocks Classsified, p. 170.

‡ Mikroskopische Beschaffenheit, p. 404.

	Leucite Rock (Wedding).	Dolerite (Durocher's).	Dolerite (Durocher's).	Felsi-(trachy-) dolerite.	Porphyrite.	Trachyte (Durocher's).	Felstone (Durocher's).	Felstone (Aran-Mowddwy).	Altered ash (Cumberland).
		mean	max.		mean	mean	mean		
Silica	48·02	51·0	55	60·718	61·5	72·8	75·4	83·802	69·673
Alumina	20·78	14·0	16	14·894	15·5	15·3	15·0	7·686	14·492
Potash	7·12	0·2	1	2·354	2·5	6·4	3·1	2·161	4·554
Soda	3·65	3·4	5	2·843	2·5	1·4	1·3	4·229	3·017
Lime	10·18	10·0	13	6·048	3·5	0·7	0·8	·896	2·296
Magnesia	1·16	5·5	9	1·909	1·5	0·9	1·1	·109	·324
Ferrous oxide	7·97	14·7	18	6·426	7·5	1·7	2·3	·408	2·784
Ferric oxide				1·405				·111	·442
Bisulphide of Iron ...	....	......	......	·395	......	......	......	·191	·410
Phosphoric acid	....	......	......	·281	......	......	......	·089	·343
Sulphuric acid	....	......	......	·103	......	......	......	·017	·205
Carbonic acid	....	......	......	1·660	......	......	......	trace	·660
Loss on ignition	....	1·1	3	·964	......	0·8	1·0	·301	·800

If these rocks do not fall strictly under any recognized name, I would suggest that for the present they should be regarded as intermediate forms similar to the trachy-dolerites, and therefore they might be included under the name *Felsi-dolerite,* denoting a combination of felsitic and doleritic characters. To such I would give the following provisional and general definition:—

Felsi- (Trachy-)dolerite.—Silica 59–61 per cent. Matrix generally crystalline, containing crystals of labradorite or oligoclase, and orthoclase, porphyritically imbedded, round which the small crystalline needles seem frequently to have flowed; magnetite generally abundant, and augite tolerably so, though usually changed into a soft dark-green mineral; apatite, and perhaps olivine, as occasional constituents. The rock usually of some shade of blue or dark green, and generally weathering white round the edges, but to a very slight depth; it frequently assumes a tabular structure, the tabulæ being often curved, and breaks with a sharp, conchoidal, and flinty fracture.

g. *Conclusion.*—In conclusion, I would again point to the intense amount of alteration these old lavas have undergone, obliterating much of their original character. Many of these rocks, especially some of the volcanic centres, such as Castle Head, Keswick, might be called diabase, chlorite being a constant constituent. Mr. Allport has traced true dolerites as far back as Carboniferous times; and it may be that in rocks so much older, as are these of Lower Silurian age, there will be found—owing *perhaps* to greater metamorphism—no lavas with a closer likeness to modern basalts than those of Cumberland, just as the ancient felstone lavas are sufficiently distinct from their modern representatives the trachytes.

Be this as it may, the undoubted fact remains that in Lower Silurian times there existed in Cumberland volcanoes of sufficient magnitude, and remaining active for a sufficient period of time, to accumulate a thickness of at least 12,000 feet of volcanic products. This great thickness of lava and ash is unmixed, except quite at the base, with strata of an *ordinary* sedimentary character; the ashy beds contain no fossils of any kind; and although there frequently occur considerable thicknesses of well-bedded material, yet the bulk is either unstratified or but very rudely stratified, and conglomeratic ash is *almost* unknown*. These facts seem to warrant the conclusion that in the main the old Cumberland eruptions were subaerial. Since a few bands of Skiddaw slate occur interbedded with the volcanic rocks at the very base of the series, it seems probable that eruptions commenced beneath and among the waters of the Skiddaw-slate sea, but that, either by elevation or the partial filling-up of the shallow sea-bed, the eruptions soon become almost wholly subaerial. In some districts there may have occurred extensive sheets of water, in which much of the finer ash was stratified, but in which the conditions were not such as to support life, at all events in any quantity. Certainly one of the main centres of eruption was close to the present site of Keswick; and in the low, wooded, and craggy hill called Castle Head one sees the stump of an old Cumberland volcano which once poured out its lava-sheets and scattered ashy material for many miles. While denudation has destroyed all semblance of volcanic form, there yet remain at some little distance from the old vent the broken ends of beds of lava and ash (such as those of Wallow Crag) which were once continuous upwards to a point far above the present summit of Castle Head. Other centres may, and certainly do, exist in other parts of the district; but that of Keswick was perhaps one of the chief, and around it occur the greatest number of lava-flows.

It might be supposed that the great granitic masses in the south-western and other parts of the district bore relations to the volcanic rocks similar to those Prof. Geikie and Mr. Judd have shown probably to have prevailed between many of the granitic bosses and accumulations of volcanic rocks in Scotland. But, since the *whole thickness* of the Cumbrian ashes and lavas are metamorphosed around the Eskdale granite, and there seems no direct connexion in chemical composition between the highly silicated granitic masses and the *somewhat* basic lava-flows, it would be rash to infer that those granitic centres *we now see* represent *immediately* the roots of the old volcanoes. When all the igneous masses of this district have been thoroughly examined more may be said upon this point.

General Results.

1. The microscopic examination of *rock-structure* teaches us much —of the conditions under which the volcanic rocks originated, and the order of their mineral structure.

2. The more ancient volcanic rocks are intensely altered, their *original* structure in *some* cases being probably completely obliterated.

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* The few cases of slight thicknesses of ashy conglomerate occur near the base of the series.

3. The Lower Silurian lavas of Wales, so far as yet examined, all belong to the felstone (= modern trachytic) group.

4. The Lower Silurian lavas of Cumberland, of about the same age as those of Wales, belong to the basaltic group, or stand somewhere midway between it and that of the felstones.

5. In both Wales and Cumberland, felspathic ashes have been metamorphosed into very felstone-like rocks.

6. Neither the careful inspection of hand-specimens, nor the microscopic examination of thin slices, would in *all* cases enable truthful results to be arrived at in discriminating between trap and altered ash-rocks; but these methods, and that of chemical analysis, must be accompanied oftentimes by a laborious and detailed survey of the rocks in the open country, the various beds being traced out one by one, and their weathered surfaces particularly noticed.

7. In the present case, the microscopic examination of the Cumberland rocks, especially when accompanied by a comparison with those of Wales, tends most decidedly to confirm the mapping of previous years.

Supplementary Note.

Since the above paper was read I have examined minutely some of the free quartz in the Snowdon felstone. Within the quartz space seen in fig. 19 are many liquid-cavities; some of these are purposely magnified three times the rest of the figure to make them visible. The majority are about $\frac{1}{10,000}$ inch in diameter, and contain vacuities moving freely in the liquid. The relative size of these vacuities to the liquid-cavities is from ·250 to ·300, a value similar to that obtained by Mr. Sorby in the case of quartz in the trachyte of Ponza. I think, indeed, that there is every reason to believe that the highly silicated Welsh felstones correspond to the modern quartz trachytes.—J. C. Ward.

EXPLANATION OF THE PLATES.

Plate XVII.

Italian.

Fig. 1. Trachyte from the Solfatara, near Naples, ×40.
2. Trachyte from the Solfatara, near Naples. Viewed with polarized light, ×15.
3. Leucitic basalt, Vesuvius, lava of 1631, Torre dell' Annunziata, ×15.
4. Leucitic basalt, Vesuvius, lava of 1794, Torre del Greco, ×6.
5. The same, more highly magnified. The upper piece of augite is the south-western corner of the upper crystalline group in fig. 4, ×45.

Cumberland.

6. Porphyritic dolerite, Eycott Hill, Cumberland, ×25.
7. Basalt, Brown Knotts, near Keswick, ×30.
8. Trap, Latterbarrow, Wastwater. Viewed with polarized light, ×15.
9. Altered ash with broken crystals, Bleaberry Fell, near Keswick, ×60.
10. Bedded ash, Steel Fell, near Wythburn. Viewed with polarized light, ×15.
11. Altered streaky ash, Base Brown, Borrowdale, ×15.

PLATE XVIII.

Fig. 12. Altered streaky ash, Base Brown, Borrowdale. Viewed with polarized light, ×15.

13. Altered ash, Hart Side, north of Glencoindale Head, ×20.
14. Altered fine-bedded ash, Great Gable, ×50.
15. Highly altered ash, Rigghause End, Vale of St. John. Viewed with polarized light, ×40.

Wales.

16. Felstone, Aran Mowddwy. Also represents the structure of fig. 15 when viewed with plain light, ×40.
17. Felstone, Aran Mowddwy. Viewed with polarized light, ×40.
18. Felstone, Aran Benlynn, ×50.
19. Upper part of Felstone, Llanberis Route, Snowdon, ×80.
20. "Slaggy felstone," Llanberis Route, Snowdon, ×15.
21. Fine-bedded ash, Glaslyn, Snowdon. Viewed with polarized light, ×40.
22. Ash, below the Aran felstones, ×35.

The figures were sketched and coloured direct from the microscope, by the author.

DISCUSSION.

Mr. FRANK RUTLEY stated that he had examined many of the microscopic sections upon which much of the author's evidence was based, and he believed that Mr. Ward was, in the main, correct in his conclusion that many of the rocks designated trap were intermediate between dolerite and felstone; for sections from one end of the series presented the character of true basalt, while others from the opposite end appeared, under the microscope, to be true felstone—a variety of sections having also been cursorily examined which passed, by almost imperceptible gradations, from the dolerites to the felstones. He considered that Mr. Ward had done as much in the determination of these rocks as it was possible to do by the examination of merely ready-mounted sections—although, from this method of investigation having been the only one at the author's disposal while working in the field, he thought that the evidence regarding some of the component minerals was scarcely satisfactory; and he adverted to the importance of examining sections of rocks by other tests than that of mere microscopic scrutiny prior to the final mounting of the preparations. He was inclined to regard some of the ashes, of which sections were exhibited, as volcanic ejectamenta, imbedded in a base much resembling devitrified, or partially devitrified matter allied to pitchstone; and he could not agree with the author in regarding the fluxed character of this base as a structure superinduced by metamorphism, at all events not in the restricted sense of that term.

Mr. KOCH thought that the flow of materials around crystals may be due to secondary actions. The effects of tension applied to molten matter may produce appearances similar to those described by the author. The study of the optical properties of crystals produced under tension would, he considered, materially assist in the determination of the nature of the crystals in rock-masses. He regarded chemical analysis as not furnishing a sufficient test.

Mr. FORBES remarked that too much stress should not be laid upon the apparent order in which the constituents in a lava had crystallized or solidified, as it had been experimentally proved that this order was not necessarily that of their fusing-points, and cited, as an example to be seen every day on the large scale, the Pattinson process for desilverizing lead, in which the lead is seen to solidify in crystals at a temperature at which the infinitely less fusible silver remains fluid. As a rule he had not found any difficulty in distinguishing, under the microscope, between a normal lava and one which had become reconsolidated from its ash or tuff, and protested against the very frequent application of the term Volcanic Ash to beds which were true volcanic tuffs. In answer to the question as to what was the difference between ashes and tuffs, he defined ashes as purely subaerial formations, thrown out of the volcanic orifice, and falling down on to land or sea as the case happened; whilst tuffs, on the contrary, were molten lava poured out into or more often under water, and thus instantaneously quenched and disintegrated into fragments or powder more or less fine in proportion as the action of the water was overpowering. In ashes each separate particle bore on its exterior the evidence of its having been exposed to the action of fire in the throat of the volcano, and externally is altered, glazed, or coated with a crust or skin, often resembling that of a meteorite, an appearance which is never to be observed in tuffs.

Prof. RAMSAY said that he thought Mr. Ward was on the right track, and that the microscopic study of rocks must lead to most valuable results. He rejoiced to find that the determination of the nature of the rocks of the Welsh district, made by the Geological Survey some thirty years ago, was now confirmed by microscopical research. This seemed to show that the larger features of a district might be worked out without the aid of a microscope. He stated that his conclusion was that the ashes had been thrown out of Old Silurian volcanoes, first beneath the surface of the sea, and afterwards above water as the vents increased in height. In the Cumbrian area, after the very earliest eruptions there, the volcanoes were subaerial, and greenslates were fine ashes thrown out upon land.

Mr. BONNEY stated that he had recently examined the "Green-Slates-and-Porphyries" series, and wished to bear testimony to the value of Mr. Ward's researches, and the great difficulty of determining some of the metamorphosed rocks. There was, however, no doubt that the latter, notwithstanding the extent to which, through metamorphism, they simulated the appearance of igneous rocks, were originally stratified volcanic ashes or tuffs. He had not yet been able to examine his own specimens microscopically; but so far as he could determine without that, he should class some as diabase, others as "porphyrite." He called attention to the remarkable lithological correspondence between the "Green-Slate" series of the Lake District and the so-called Cambrian of Charnwood Forest, the volcanic breccias, ashes or tuffs, and hornstones of both being often very similar. It was remarkable that the strike of these "Green

Slates," when last seen to the S.E., was about W.N.W., which corresponded nearly with the Charnwood strike. Hence he thought it possible that they might be of the same age.

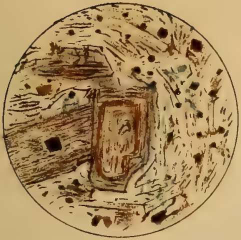
Mr. Judd remarked that the circumstances connected with the mode of occurrence of certain very important rock-constituents, such as leucite, haüyne, nosean, mellilite, &c., seemed to point to the conclusion that species of minerals may present peculiarities of distribution, both in space and time, analogous to those of animal and vegetable species. He suggested the necessity of constantly keeping in view such a possibility when making comparisons between ancient and modern volcanic rocks.

Mr. Blanford inquired whether the ancient traps are not distinct in their origin from true lavas. In India large districts are formed of volcanic rocks much more recent than those of Wales, and probably of different composition. These Indian flows are of great horizontal extent, but of small thickness.

Mr. Forbes stated that the Indian rocks in question which he had examined were not distinct from our basalts in composition and structure, which showed that they were not poured out under water.

Mr. Ward replied as follows:—To Mr. Rutley, that the *flow* described as occurring in some of the altered ash-rocks was *not* a decided crystalline flow, but one merely of chloritic material around the larger fragments, and frequently along the bedding planes. To Mr. Forbes and Mr. Koch, that the analyses brought forward had been made from specimens carefully collected in the field, and might be considered as representing the average chemical composition; the author used the word *ash* as denoting all material shot out from a volcano; in this case the ashes were mostly subaerial. To Mr. Bonney, that although the analyses of the Cumberland lavas were very similar to those of porphyrites, the microscopic structure of the latter, as described by Zirkel, did not at all correspond with that of the Lake-district rocks. To Mr. Blanford, that the Cumberland contemporaneous traps were as much entitled to the name of lavas as any modern Vesuvian flow.

1.



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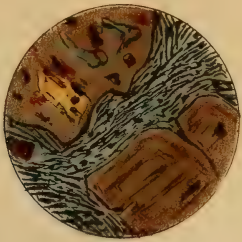

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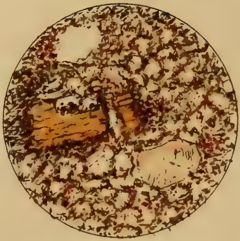

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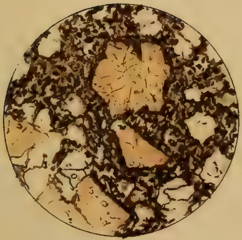

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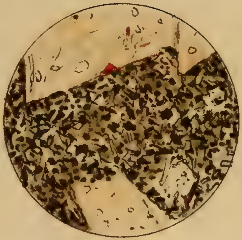

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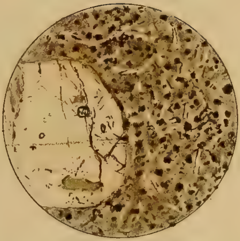

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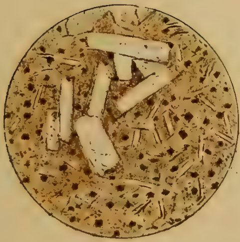

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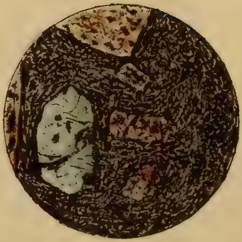

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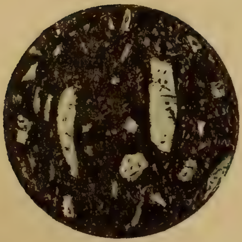

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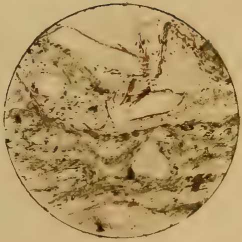

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G. H. Ford.

Mintern Bros. imp.

SECTIONS OF VOLCANIC ROCKS.

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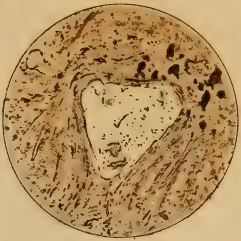
13.



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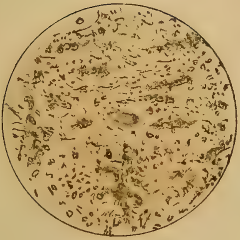

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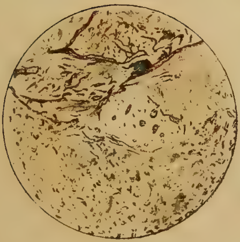

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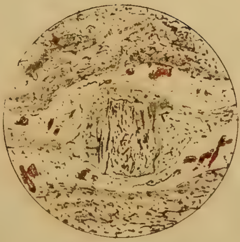

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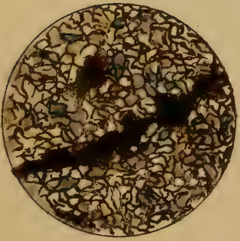

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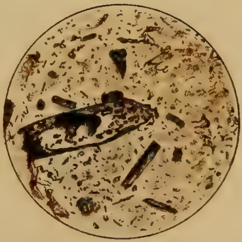

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SECTIONS OF VOLCANIC ROCKS.

27. *On* STAGONOLEPIS ROBERTSONI, *and on the* EVOLUTION *of the* CROCODILIA. By Prof. THOMAS H. HUXLEY, LL.D., Sec. R.S., F.G.S. (Read April 28, 1875.)

[PLATE XIX.]

NEARLY seventeen years ago I had the honour of laying before the Geological Society * an account of such remains of a remarkable reptile (*Stagonolepis Robertsoni*) as, up to that time, had been found in the sandstones of the neighbourhood of Elgin, and the conclusion at which I had arrived, "that *Stagonolepis* is, in the main, a Crocodilian reptile."

These remains, however, like all the other fossils from the same district which have come under my notice, were not in a condition very favourable to their interpretation. With the exception of a few dermal scutes, I do not think that a single entire bone, or cast of a bone, has come into my hands; and the most instructive specimens have not been the bones themselves, the osseous matter being always soft, friable, and injured, but their casts in the sandstone. The evidence afforded by the remains of vertebræ and scutes was sufficiently decisive to warrant my conclusion as to the general nature of the animal; but, in respect of the other parts of the skeleton, the surmises which I made in 1858 needed confirmation, or the reverse, by the study of additional materials.

Such materials have from time to time been obtained by the exertions of my friend the Rev. Dr. Gordon, of Birnie, near Elgin, who, aided by a grant from the Donation Fund of the Royal Society, has undertaken the exploration of the fossiliferous beds whenever the operations of the quarrymen laid them bare, and has from time to time sent me consignments of valuable and instructive specimens. From these and others, for which I am indebted to Mr. Grant of Lossiemouth, I have been enabled to make numerous important additions to my knowledge of *Stagonolepis*; so that at present I am acquainted with the following parts of its skeleton:—

1. The dermal scutes, which formed a dorsal and a ventral armour.
2. Vertebræ of the cervical, thoracic, lumbar, sacral, and caudal regions.
3. Ribs.
4. Parts of the skull and teeth.
5. The scapula, the coracoid and the interclavicle.
6. The humerus and (probably) the radius.
7. The ilium, ischium, and pubis.
8. The femur and (probably) the tibia.
9. Two metacarpal or metatarsal bones.

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* "On the *Stagonolepis Robertsoni* (Agassiz) of the Elgin Sandstones." —Quart. Journ. Geol. Soc. 1859

Under these circumstances, it is possible to form a distinct and tolerably complete conception of the nature of *Stagonolepis*, and to compare it with other reptiles, so as to arrive at a just notion of its affinities.

So far as the vertebræ, ribs, scapula, and dermal armour are concerned, I have nothing to alter in the views which I took of the nature of the bones and their systematic significance in 1858. The bone which, in the body of my paper, I interpreted as a coracoid, turns out to have been correctly identified; while that referred to in the note at p. 459, and which led me to doubt whether I was right in this interpretation, has been shown by better specimens to have been an ilium seen from the inner side. The distal moiety of a limb-bone, which is regarded as a femur at p. 452, is shown, by further evidence, to be a humerus; and, finally, the mandible with long curved teeth, which I supposed might belong to *Stagonolepis*, certainly appertains to some other animal.

It is a very remarkable circumstance that, up to the present date, the fossiliferous sandstones of Elgin have yielded remains of *Stagonolepis* (several individuals, some of which must have attained a length of 12 or 14 feet), of *Hyperodapedon* (one almost complete specimen, half another, and fragments of others, the largest probably 6 feet long), of *Telerpeton* (two nearly entire specimens about a foot long), and of the large animal to which the mandible with long curved teeth belonged, and absolutely nothing else. Not a trace of other vertebrate or invertebrate animals, or of plants, has yet been detected; and the only other indication of life is the well-known series of foot-prints, which, so far as I can ascertain, do not occur in the same beds with the reptilian remains. As *Stagonolepis*, at any rate, was a carnivorous animal, and must have needed a considerable supply of aliment, the absence of any trace of the animals on which it fed (unless, as is not very likely, it devoured Lizards) is a curious illustration of the value of negative evidence.

From the evidence which has now been collected, and which consists entirely of specimens associated with the characteristic scutes of *Stagonolepis*, it is demonstrable that, in outward form, this reptile must have resembled one of the Caimans or Jacares of the present fauna of intertropical America, that it possessed strong limbs, of which the anterior were at least as large, in proportion to the posterior, as in the modern *Crocodilia*, but that *Stagonolepis* differed from the Caimans in possessing a long and narrow skull, more like that of a Gavial.

As in the existing Caimans and Jacares, the trunk and tail were protected by a strong armour, composed of a dorsal and a ventral set of thick bony dermal scutes, which, in the trunk, were so arranged as to constitute separate dorsal and ventral shields, while in the tail they formed a continuous girdle. In contradistinction to existing *Crocodilia*, the dorsal shield was made up of not more than two longitudinal series of scutes, and the ventral shield of not more than eight series in any part.

The dorsal scutes are angulated and longitudinally keeled on their free surfaces; the ventral scutes are flat, and formed of a single ossification.

The free surfaces of the scutes have a deeply pitted or grooved sculpture. The vertebræ (except doubtless the atlas and axis) are amphicœlous, the anterior and the posterior surfaces of their centres being alike slightly concave. The transverse processes resemble those of Crocodiles; and, as in some recent *Crocodilia* (e. g. *C. niloticus*) and in *Belodon,* those of the anterior thoracic vertebræ are inclined upwards.

The transverse processes of the lumbar vertebræ, of which there were not fewer than two, are long, broad, and directed horizontally, those of the last lumbar vertebra being wider at their outer than their inner ends.

The sacrum consists of two unankylosed, amphicœlous vertebræ; and the ends of the sacral ribs are remarkably wide—more so in proportion than in any Crocodile known to me.

The centrum of the first caudal vertebra is amphicœlous. The skull is produced into a slender rostrum; and the rami of the mandible are united in a long symphysis. The posterior nares are situated far forward, as in Lizards; and neither the palatine nor the pterygoid bones unite to prolong the nasal passage backwards and give rise to secondary posterior nares, as in existing Crocodiles. In the mode of formation of the proper posterior nares, however, *Stagonolepis* conforms to the Crocodilian type.

All the teeth which I have reason to refer to *Stagonolepis* have short, swollen, obtusely pointed crowns, like the back teeth of some existing *Crocodilia,* and they sometimes exhibit signs of wear by mutual attrition.

In the pectoral arch, the scapula resembles that of recent Crocodiles; but the coracoid is short and rounded, like that of the *Ornithoscelida,* and of some existing Lizards, such as *Hatteria.*

As in existing Crocodiles, there is an interclavicle, but no clavicles.

The humerus is more Lacertian than that of existing Crocodiles in the expansion of its ends, and the presence of a ridge and groove on the radial side of its distal end.

The ilium differs from that of existing Crocodiles and is more Lacertian, in the large size of the ala, especially in front, and in the forward prolongation of its anterior dorsal angle; further, in the shape of the ventral margin of the acetabular portion of the bone, and in the absence of any notch or excavation in that margin.

The acetabular end of the ischium resembles that of a Lizard, and not that of a Crocodile; and the rest of the bone is shorter dorsoventrally, and longer antero-posteriorly, than in recent Crocodiles, in both which respects it closely resembles *Belodon.* The distal end of the femur is narrower in proportion to its proximal end and to the distal end of the humerus than in recent Crocodiles.

Among known forms of Reptilia, the nearest ally of *Stagonolepis* is undoubtedly the *Belodon* of the Upper Keuper of Württemberg, the remains of several species of which have been well figured and described by the late Hermann von Meyer *, who makes known the characters of vertebræ of various regions (though none from the sacrum), very perfect crania and teeth, the scapula, coracoid and humerus, the ilium and the femur. Moreover, during a brief visit to Stuttgart in 1873, Herr Kapff had the goodness to show me a well-preserved pelvis, with the ischium in place.

An extensive comparison can therefore be instituted between *Stagonolepis* and *Belodon*; and it proves that the two genera closely resembled one another, but, nevertheless, were separated by many differential characters. For example, the teeth are totally different. So far as the nasal apertures are concerned, *Stagonolepis* agrees generally with *Belodon*, though the form both of the external and the posterior nares was different. But there can be no doubt that *Stagonolepis* and *Belodon* are members of one and the same natural group, and that this group must be included among the order *Crocodilia*.

The *Crocodilia* are defined from all other Reptilia, whether recent or extinct, by the following characters:—

The transverse processes of the majority of the cervical and thoracic vertebræ are divided into more or less distinct capitular and tubercular portions; and the proximal ends of the ribs which appertain to these vertebræ are correspondingly divided into capitula and tubercula. The dorsal ends of the subvertebral caudal bones are not united; the quadrate bone is fixed to the side of the skull; the pterygoid bones send forward median processes, which separate the palatines, and reach the vomers.

There is an interclavicle, but no clavicles. The ventral edge of the acetabular portion of the ilium is entire, or but slightly exca-

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* "Reptilien aus dem Stuben-Sandstein des obern Keupers."—'Palæontographica,' Bände vii., x., xiv. 1861–1865.

Professor Cope ("Synopsis of the Extinct Batrachia and Reptilia of North America,"), writing in 1869, and therefore with all the materials for forming a judgment afforded by Von Meyer's publications, takes a very different view of the affinities of *Belodon* from that here adopted.

"*Thecodontia* (Owen).

"In this suborder we have a singularly generalized group, combining characters of Lizards, Crocodiles, and Sauropterygians. The neural arch of the vertebræ, united by suture, and the slightly biconcave centrum, resemble the last two, as also the abdominal ribs. The limbs are rather Crocodilian, the position of the nares Plesiosaurian. The clavicle is Lacertian, while the three vertebræ of the sacrum and the femur are between these and the *Dinosauria*. The most important characters distinguishing these animals from the Sauropterygia are the presence of an elongate sacrum and the more ambulatory form of the limbs. Our knowledge of this order is almost confined to *Belodon* (Meyer), and is derived from that author's descriptions of three large and remarkable reptiles derived from the Keuper of Württemberg—the *Belodon Kapfii* (Meyer), *B. Plieningeri* (Münst.), and *B. planirostris* (Meyer)."

Where did Professor Cope obtain his information respecting the "clavicle" and the sacrum of *Belodon*?

vated. The ischia are not greatly prolonged backwards; and the pubes are directed forwards and inwards.

The femur has no prominent inner trochanter; the astragalus is not a depressed concavo-convex bone with an ascending process. There are, at fewest, two longitudinal rows of dermal scutes, one on each side of the middle line of the dorsal region of the body.

Stagonolepis and *Belodon* come within the order *Crocodilia*, as thus defined, and constitute the first of three suborders, which may be distinguished on purely anatomical grounds.

Suborder I. PARASUCHIA.

Neither the palatine nor the pterygoid bones are produced into osseous plates which prolong the nasal passage and give rise to secondary posterior nares. Consequently the nasal chambers communicate with the mouth by apertures situated beneath the anterior part of the skull. The Eustachian passages are not enclosed by bone. The centra of the vertebræ are amphicœlous. The atlas and axis are unknown. The coracoid is short and rounded. The ala of the ilium is high, and has a large and prominent anterior dorsal angle. The acetabular margin is entire, and its centre projects beyond its anterior and posterior ends. The ischium is short dorso-ventrally, elongated longitudinally, and in its acetabular portion resembles that of a Lizard. The characters of the manus and pes are unknown.

There are two longitudinal series of articulated, carinated, dorsal scutes; and in *Stagonolepis* (but apparently not in *Belodon*) there is a ventral thoraco-abdominal shield, formed of not more than eight longitudinal series of articulated scutes, each of which consists of only one piece of bone.

Genera. *Stagonolepis, Belodon.*

Suborder II. MESOSUCHIA.

The palatine bones are produced into osseous plates, which prolong the nasal passages and give rise to secondary posterior nares, which are situated beneath the middle of the skull. The pterygoid bones take no share in the formation of the secondary posterior nares.

A middle Eustachian canal is included between the basioccipital and the basisphenoid, but the lateral Eustachian canals of existing Crocodilia are represented only by grooves*.

The centra of the vertebræ are amphicœlous. The coracoid is elongated, as in the next suborder. The ala of the ilium is less high than in the foregoing, higher than in the following suborder. Its antero-dorsal angle is at most only slightly prolonged. The acetabular margin is nearly straight, and hardly, if at all, notched.

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* M. Eudes Deslongchamps was the discoverer of this and many other important characters of the skull, and, indeed, of the general structure of the Mesosuchia. See the classical "Prodrome des Téléosauriens du Calvados," contained in the 'Notes Paléontologiques,' published by M. Eugène Eudes Deslongchamps in 1869.

The ischium is more elongated dorso-ventrally, and is shorter antero-posteriorly, than in the *Parasuchia*. Its acetabular margin is excavated by a deep notch, which marks off a stout pubic process, as in the next suborder.

The manus and pes are constructed as in the next suborder*. There are two longitudinal series of dorsal scutes, some of which are longitudinally carinated; and in most, if not all, of the members of this suborder there is a ventral thoraco-abdominal shield composed of not more than eight longitudinal series of undivided flat scutes.

Genera. *Steneosaurus, Pelagosaurus, Teleosaurus, Teleidosaurus, Metriorhynchus,* (*Goniopholis?, Pholidosaurus?*).

Suborder III. Eusuchia.

Both the palatine and the pterygoid bones are produced into osseous plates, which prolong the nasal passages backwards, and give rise to secondary posterior nares, situated beneath the hinder part of the skull.

The centra of the vertebræ which succeed the atlas and axis are procœlous, except in the two sacral vertebræ, the opposed faces of which are flat, and the first caudal, the centrum of which is doubly convex.

There is always a middle Eustachian passage enclosed between the basisphenoid and basioccipital, and usually two lateral Eustachian canals likewise enclosed by bone.

The coracoid is elongated.

The ala of the ilium is so low in front as to be almost obsolete; and there is a mere rudiment of an antero-dorsal process. The acetabular margin is deeply notched.

The ischium is elongated dorso-ventrally, and short antero-posteriorly. Its acetabular margin presents a deep excavation, in front of which is a strong process for articulation with the pubis. There are two elongated and constricted proximal carpal bones, and five digits in the manus. In the pes the calcaneum has a strong backward process, and the fifth digit is rudimentary.

There are always more than two longitudinal series of carinated dorsal scutes; and when ventral thoraco-abdominal armour exists, it contains more than eight longitudinal series of scutes.

The ventral scutes are made up of two ossifications united suturally†.

It is obvious, from the mere statement of the characters of these three suborders, that the group which I have termed *Mesosuchia* is intermediate between the other two. It is further plain that the

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* See d'Alton and Burmeister, 'Der fossile Gavial von Boll,' p. 57, and Taf. vii.

† See my papers "On the Dermal Armour of *Crocodilus Hastingsiæ*," Quart. Journ. Geol. Soc. 1859; "On the dermal Armour of *Jacare* and Caiman, with notes on the specific and generic characters of recent Crocodilia," Proc. Linn. Soc. 1859; and "Etude zoologique sur les Crocodiliens Fossiles Tertiaires," by Dr. Léon Vaillant (Annales des Sciences Géologiques, 1872).

Parasuchia, in those respects in which they differ from the *Mesosuchia,* approach the *Ornithoscelida* and *Lacertilia,* especially such *Lacertilia* with amphicœlous vertebral centra as the existing *Hatteria* and the extinct *Hyperodapedon,* the affinities of which I have elsewhere indicated*. In fact I know of no other reptile in which the skull and pectoral arch so nearly approach the structure found in *Belodon* and *Stagonolepis* as they do in *Hatteria.* On the other hand, the *Eusuchia* are those *Crocodilia* which depart most widely from the *Ornithoscelida* and *Lacertilia,* and are the most Crocodilian of Crocodiles.

The differences between the *Mesosuchia* and the *Eusuchia* are of no great moment. The MM. Deslongchamps, in the remarkable memoir to which I have referred, show that in *Metriorhynchus,* which ranges from the Kelloway rock to the Kimmeridge clay, the secondary posterior nares are carried further back than in *Pelagosaurus,* which is confined to the Upper Lias. Let the pterygoids of *Metriorhynchus* begin to unite, and let the posterior faces of the centra of its vertebræ, instead of being a little concave, become a little convex, and it would furnish a perfect transitional form between the *Mesosuchia* and the *Eusuchia.*

On the other hand, the *Parasuchia,* in the conformation of the posterior and the position of the anterior nares; in the non-enclosure of any part of the Eustachian canals by bone; and in the configuration of the coracoid, depart much more widely from the *Mesosuchia,* closely connected with the latter as they are by their dermal armour and in other ways.

From a purely morphological point of view, then, these three suborders of the *Crocodilia* form a series, slightly interrupted between the *Eusuchia* and the *Mesosuchia,* but with a larger gap between the latter and the *Parasuchia.* But whatever the value of the breaks between the three terms of the series, it is clear that the modifications which are needed to connect one term with another are of the simplest kind, and are throughout of the same order. The kind of change which would convert a Parasuchian Crocodile into a Mesosuchian, would, if continued, convert a Mesosuchian into a Eusuchian. Hence, if there is any valid historical foundation for the doctrine of evolution, the *Eusuchia* ought to have been developed from the *Mesosuchia,* and these from the *Parasuchia;* and if this process of evolution has taken place under such conditions that the skeletons of the *Crocodilia* which have been subject thereto have been preserved, geological evidence should show that the *Parasuchia* have preceded the *Mesosuchia,* and the *Mesosuchia* the *Eusuchia,* in order of time.

Now this is exactly what the geological evidence does prove. It is established that these reptiles appear in the following order :—

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* "On *Hyperodapedon,*" Quart. Journ. Geol. Soc. 1869, p. 147.

PARASUCHIA.

Trias. *Belodon, Stagonolepis.*

MESOSUCHIA.

Lower Lias.		
Upper Lias.	*Steneosaurus, (Mystriosaurus), Pelagosaurus.*	
Inferior Oolite.	*	
Fuller's Earth.	* *Teleosaurus, Teleidosaurus.*	
Great Oolite.	*	
Kelloway Rock.	*	
		Metriorhynchus.
Oxford Clay.	*	*
Coral Rag.	*	
Kimmeridge Clay.	*	*
Portland Oolite.		
Wealden.	*Goniopholis, Macrorhynchus, Pholidosaurus,* and unnamed Teleosaurians.	
Lower Greensand.		
Gault.		
Upper Greensand.		
Lower Chalk.		
Upper Chalk.	*Hyposaurus.*	

EUSUCHIA.

Thoracosaurus, Holops, Gavialis (?).

This table shows that the order in which the three divisions of the *Crocodilia* make their appearance is the same as the order of their departure from the Lacertilian, and approach to the highly specialized Crocodilian, type.

How far back the range of the *Parasuchia* extends we have no means of judging. Nothing is known of them, at present, subsequently to the Upper Trias. Of the two known genera, *Stagonolepis* would seem to approach the *Mesosuchia* somewhat more closely than *Belodon* does, but it is far on the Parasuchian side of the boundary line between the two suborders. There is a hiatus in our knowledge of the *Crocodilia* answering to the Lower Lias, from which, up to this time, no Crocodilian remains are certainly known. With the Upper Lias our acquaintance with the *Mesosuchia* commences; and they are represented, without interruption, as far as the Wealden inclusively. Then follows a great break, answering to the Greensands, Gault, and Lower Chalk, during which period there is no evidence as to the characters of the Crocodilia.

It is at the end of this unrepresented interval that the *Eusuchia* make their appearance, under forms exceedingly similar to the existing long-snouted Crocodiles. Nevertheless the *Mesosuchia* persisted until the end of the Cretaceous epoch. The ranges of the *Eusuchia* and the *Mesosuchia* therefore overlap in the later Cretaceous epoch, where the *Eusuchia* are represented in the Greensands of New Jersey* by *Thoracosaurus* (Leidy), *Holops* (Cope), and other forms, and the *Mesosuchia* by *Hyposaurus* (Owen). On this side of the Atlantic the *Gavialis macrorhynchus* of the "Calcaire pisolithique" of Mont Ariné (Upper Cretaceous) and the Maestricht Chalk † is a completely differentiated Eusuchian.

It is interesting to observe that *Thoracosaurus* has large prælachrymal vacuities like a Teleosaurian, and that the opening of the median Eustachian canal is "a large transversely oval pit" (Leidy, *l. c.* p. 7). The subvertebral processes of the cervical vertebræ are small and divided. Leidy figures a biconvex first caudal vertebra, though it is not certain that it belonged to this genus. I am inclined to suspect that the scute of *Thoracosaurus*, "without any trace of carina" (*l. c.* p. 11), indicates ventral armour.

Hyposaurus had amphicœlous vertebræ; but Leidy states that the anterior concavities of these vertebræ are more deeply depressed than the posterior (*l. c.* p. 20).

On the other hand, *Holops* and *Gavialis macrorhynchus* appear to differ very little from existing *Crocodilia*; so that, in the case of the *Crocodilia*, as in that of many other groups, the real "dawn" of the existing fauna is not in the Eocene, but in the latter part of the Cretaceous formation.

Thus the facts relating to the modifications which the Crocodilian type has undergone since its earliest known appearance, are exactly accordant with what is required by the theory of evolution; and the case of the Crocodiles is as cogent evidence of the actual occurrence of evolution as that of the Horses.

It must be understood that in maintaining that the *Crocodilia* were at first *Parasuchia*, then *Mesosuchia*, and lastly *Eusuchia*, I do not suggest that the progression has been effected through the forms with which we happen to be acquainted. At the present day there are two extreme terms of the Crocodilian series, the Gavials being modified in accordance with the needs of an almost exclusively aquatic life, and the Crocodiles and Caimans being much more terrestrial in their habits. It is probable that this distinction has been maintained, and that there have been more aquatic and less aquatic forms throughout the greater part of the existence of the *Crocodilia*.

Unfortunately the only middle Mesozoic *Crocodilia* with which we are well acquainted are the marine, probably sublittoral forms of *Mesosuchia*, such as *Teleosaurus* and *Steneosaurus*; while the older Mesozoic *Crocodilia* are the probably freshwater *Parasuchia*, of a more terrestrial habit.

Thus, before being able to construct the complete ancestral tree of the *Crocodilia*, we need to know those forms (if such existed) of *Parasuchia* which were more aquatic than *Belodon* and *Stagonolepis*—and, on the other hand, those forms of *Mesosuchia* which were less

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* Leidy, "Cretaceous Reptiles of the United States," Smithsonian Contributions, xiv. 1865. Cope, "Synopsis of Extinct Batrachia and Reptilia," Transactions of the American Philosophical Society, 1869.

† Gervais, 'Zoologie et Paléontologie Françaises,' ed. 1859, pp. 431–457.

aquatic than the Teleosaurians, and which probably haunted the estuaries and lakes of the Jurassic epoch.

In the present paper I have endeavoured to confine myself to the statement of verifiable facts, and to the conclusions obviously suggested by them; and I abstain, for the present, from dwelling on the bearing of these facts and conclusions on the relation of the *Crocodilia* to other *Reptilia*, especially the *Ornithoscelida*; but I hope to take up that subject on some future occasion.

After the preceding pages were written, it occurred to me that a fragment of a Crocodilian skull from the Wealden of Brook Point, in the Isle of Wight, which has been for many years in the Museum of Practical Geology, might possibly yield some information as to the condition of the secondary posterior nares in the *Crocodilia* of that epoch. The region in which these apertures should occur was thickly covered with matrix; but when the latter was removed, very skilfully and carefully, by Mr. Newton, Assistant Naturalist in the Museum of Practical Geology, it revealed the palatine and pterygoid bones, with the base of the skull behind them, in an almost uninjured state (Plate XIX. fig. 3).

Nothing could be more instructive than the condition of these parts. The nasal passage is narrower, and the posterior palatine foramina are larger, in proportion to the width of the skull, than in any hitherto known Mesosuchian; the lateral processes of the pterygoids are broader, and the distance between the median Eustachian aperture and the anterior margin of the secondary posterior nostrils far less than in any. The secondary posterior nares themselves are situated relatively further back, and have not a third the dimensions they possess in *Steneosaurus* or *Metriorhynchus*. The distance between the posterior margins of the lateral processes of the pterygoids and the occipital face of the skull is greatly less. On the left side, the descending process of the postfrontal, which bounds the orbit behind, is seen. The sculpture upon its outer surface is interrupted close to its ventral end, leaving a smooth narrow groove between the orbit and the temporal fossa, which answers to the much broader groove between the orbit and the temporal fossa in the *Eusuchia*. In all these respects, this Wealden Crocodile approaches the *Eusuchia* much more closely than any previously known Mesosuchian Crocodile does; but it keeps its Mesosuchian character in the manner in which the narrow elongated oval secondary posterior nares are formed. In fact, they are bounded in front by the extreme posterior edge of the palatal plates of the palatine bones, and the pterygoids form only the lateral walls and the septum between the two. The structure therefore lies on the boundary line between that characteristic of the *Mesosuchia* and that which distinguishes the *Eusuchia*; and as it constitutes a very good generic distinction, the Wealden Crocodile might be made the type of a new genus, if we could compare it with *Goniopholis* and *Macrorhynchus*. Unfortunately there are no well-preserved teeth, and the greater part of the rostrum is absent, while we know nothing of the structure of the secondary posterior nares in either *Goniopholis* or *Macrorhynchus*.

The results obtained from the investigation of the nature and order of the successive changes which the *Crocodilia* have undergone since their first appearance in the Triassic epoch, naturally suggest the inquiry whether the nearest living and extinct allies of the Crocodiles, the Lacertilia and the Ornithoscelida, which are traceable, the former from the present day to the Permian epoch, the latter from the later Cretaceous to the Triassic epoch, exhibit any evidence of having been subjected to a similar process of evolution.

In the case of the Lacertilia, it is unfortunate that nothing of moment is known respecting the cranial structure of the Permian forms. In the rest of the skeleton it is hard to find any important deviation from the type of the existing Lizards except in the characters of the centra of the vertebræ, which are amphicœlous instead of being, as in the majority of existing Lizards, procœlous. In the Trias, the only Lacertilia at present known are *Hyperodapedon*, *Rhynchosaurus*, and *Telerpeton*; and as I have shown on a previous occasion*, the first singularly resembles the existing New-Zealand *Hatteria*, the resemblance of which to *Rhynchosaurus* had already been indicated by Professor Owen and Dr. Günther.

In the Museum of Practical Geology, there is a sacral vertebra of a Lizard from the Purbecks, with the anterior face of the centrum concave and the posterior convex. All earlier Lacertilians at present known have amphicœlous vertebral centra, while all but a few existing Lizards are procœlous.

Thus it would appear that, on the whole, the vertebral system of the Lizards has undergone a change corresponding to that which has occurred in the Crocodiles, and that this modification of the articular faces of the vertebræ took place at an earlier period in the Lizards than in the Crocodiles. Apart from this, there is no evidence that the Lacertilian type of structure has undergone any important change from the later Palæozoic times to the present day.

The discoveries of American palæontologists prove that the *Ornithoscelida* abounded in the latter part of the Cretaceous epoch, up to the very verge of the commencement of the deposition of the Tertiary rocks.

In a paper on the "Classification of the Dinosauria, with observations on the Dinosauria of the Trias," read before the Society in 1869 †, I endeavoured to show that there was evidence of the existence of varied forms of Dinosauria in the Trias, and I discussed, at some length, the case of *Zanclodon* (which is probably identical with *Teratosaurus* of von Meyer), from the Upper Keuper of Württemberg.

In 1873 I had the opportunity of paying a short visit to Stuttgart; and with the courteous permission and aid of Prof. Fraas, I examined the fine series of remains of *Zanclodon* in the museum of that city.

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* "On *Hyperodapedon*," Quart. Journ. Geol. Soc. vol. xxv. (1869) p. 138.

† Quart. Journ. Geol. Soc. vol. xxvi. (1870) p. 32.

I was thus enabled to assure myself that the rectification of Prof. Plieninger's interpretation of the bone which he terms the ischium, upon which I had ventured (*l. c.* p. 40), was fully justified. It is, in fact, the ankylosed scapula and coracoid. Both the humeri are preserved, and they are about two thirds the length of the femora. The femora resemble those of *Megalosaurus*. They have a strong inner trochanter; and there is a ridge upon the posterior face of the outer condyle. The tibia has a strong cnemial ridge, though the latter is not so prominent as in *Megalosaurus*. The left tibia and fibula, lacking their proximal ends, are preserved in almost their natural relations. The tibia could not have been more than three or four inches shorter than the femur; and its distal end is very like that of *Megalosaurus*. The fibula is a strong bone, its shaft being about half the diameter of the tibia. About half the astragalus is in place at the distal end of this tibia. It has the characteristic concavo-convex form; but its outer moiety is broken away. A rudiment of the ascending process is traceable; whether it has been broken or not is not clear. The left foot has been dislocated backwards. The proximal ends of three large separate metatarsals lie side by side; and close to them are two distal tarsal ossicles. There appear to have been four (if not five) digits.

It is unquestionable that *Zanclodon* is very nearly allied to *Megalosaurus*; and if, as I think there is little reason to doubt, the fossil named by von Meyer *Teratosaurus*, is the jaw of *Zanclodon*, the affinity is exceedingly close*. Inasmuch as the sacrum is composed of a smaller number of vertebræ than in *Megalosaurus*, it may be said that *Zanclodon* is a less differentiated form; but in the absence of a sufficiently complete knowledge of the ventral elements of the pelvis and of the skull, it would be hardly safe to come to any decided conclusion on this point.

At p. 44 of the 'Memoir on the Triassic *Dinosauria*,' to which reference has already been made, I have discussed the characters of the Thecodontosauria, and have shown grounds for arranging them among the Ornithoscelida. On one point I wish to make a correction. Acquaintance with the ilium of *Stagonolepis* convinces me that I have turned the ilium of the Thecodontosauria the wrong way—that what I have termed its anterior end is its posterior end, and *vice versâ*. The importance of this fact is that the ilium of *Thecodontosaurus* †, thus regarded, instead of being more especially Ornithoscelidan than that of *Megalosaurus*, is in reality much more

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* I carefully examined the wonderful bone which Plieninger has considered to be a sternum; and Herr Kapff was good enough to show me a fossil representing half a smaller example of the same bone. Plausible as Plieninger's interpretation appears at first sight, I must withdraw my assent to it. The large antero-lateral processes which he figures end, in front, in smooth concave faces, as if they had formed part of a large articular cavity, while at their dorsal and ventral extremities they are rough, as if they had articulated with other bones. The resemblance of these to the pleurosteal processes of the bird's sternum, suggested in my paper, does not hold when they are closely examined. I am much inclined to think that the great shield may represent coalesced ischia.

† I use this name without being able to say whether the bones in question belonged really to *Thecodontosaurus* or to *Palæosaurus* (*l. c.* p. 45).

Lacertilian; and, except for the great vacuity of the inner wall of the acetabulum, it is almost intermediate in form between the ilium of *Stagonolepis* and that of a *Monitor* or *Iguana.*

From the proportion of the ilium to the centra of the vertebræ, it is impossible that more than two vertebræ could have entered into the sacrum, which is again a point of approximation to the *Lacertilia* and *Crocodilia.*

The bone described and figured [*] by Riley and Stutchbury as an ischium is really a humerus, as I have satisfied myself by having the matrix which obscured the distal articular end of the bone cleared away. In the collection of the Bristol Museum there are two of these bones, both belonging to the right side. They are altogether similar in their salient characters to the humeri of a *Monitor.*

Another important point bearing on the affinities of the *Thecodontosauria* is the structure of the distal end of the tibia. I have shown [†] that, in the typical *Dinosauria*, the distal half of the bone is flattened, and has one face turned forwards and outwards, and the other backwards and inwards, as in birds. Unfortunately I have been able to find no tibia of *Thecodontosaurus* with the distal end perfect; but, in two specimens, enough is left to show that its distal extremity was not flattened, but was thick, with an almost circular transverse section. In fact, in this respect it resembles the tibia of a Lizard rather than that of a Dinosaurian. This structure of the distal end of the tibia necessarily involves the absence of the characteristic Ornithoscelidan astragalus. I may add that, in its form, and its approximation to the proximal end of the bone, the inner trochanter of the femur in *Thecodontosaurus* nearly resembles the same part in the *Monitor*, while in the great length of the bones of the limbs as compared with the vertebræ there is a further approximation to many Lacertian forms.

The measurements of certain bones found closely associated together enable one to form a tolerably clear notion of the proportions of *Thecodontosaurus.* A right humerus, 6·2 inches long, is associated with the proximal halves of a right femur and a left tibia. Complete specimens of femora and tibiæ of the same size as the foregoing, and lying close together, are respectively rather less than 7 inches and 7·1 inches in length. A fragment of a tibia of approximately the same size is associated with two ilia (right and left) and a centrum of a caudal vertebra. The ala of the ilium measures 4 inches antero-posteriorly. The greatest antero-posterior diameter of the acetabular portion is 2·7 inches. The centrum of the vertebra is 1·2 inch long, 0·6 inch in vertical height.

A strong curved ungual phalanx, 1·15 inches long, lies beside a caudal vertebra of the same length as the foregoing; and a similar phalanx adheres to a metacarpal or metatarsal bone, 3·5 inches long.

Thus it is clear that the *Thecodontosauria* possessed remarkably elongated and, at the same time, strong limbs, differing from those

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[*] Trans. Geol. Soc. v. pl. 30, fig. 4.

[†] "Further evidence of the affinities between Dinosaurian Reptiles and Birds," Quart. Journ. Geol. Soc. vol. xxv. (1869) pp. 19–22.

of Lizards only in the somewhat greater size and lower position of the inner trochanter of the femur, and in the large cnemial end of the tibia, but devoid of the special peculiarities observed in the ankle-joint of the typical Ornithoscelida. We unfortunately know nothing of the structure of the ventral elements of the pelvis. The ilium, as has been seen, is Lacertilian in form, Ornithoscelidan in the character of the acetabulum. But the vertebræ and the implantation of the teeth are, as in the typical Ornithoscelida, Crocodilian, and not Lacertilian.

Such evidence as the imperfect materials at present extant offer tends to show that the Triassic Thecodontosauria were devoid of some of the most marked peculiarities of the later Ornithoscelida; while, on the other hand, the most ornithic of Ornithoscelida at present known, such as *Iguanodon*, *Hadrosaurus*, *Hypsilophodon*, and *Lœlaps*, belong to the later half of the Mesozoic period.

Just as the oldest Crocodiles differ less from the Lacertilia than the recent Crocodiles do, so it appears that the oldest Ornithoscelida approached a less differentiated Lacertilian form. The Crocodilia and the Ornithoscelida appear to converge towards the common form of a Lizard with Crocodilian vertebræ.

On the evidence of such remains of *Cetiosaurus* as had come to light in 1869 I have assigned a place among the Dinosauria to that reptile. The materials subsequently brought together and described by the late Prof. Phillips do not, however, bear out this view, but show that *Cetiosaurus* is, like a Thecodontosaurian, a reptile with a vertebral system similar to that of the Ornithoscelida and Crocodilia, but with more Lacertilian limbs; and it may be that *Stenopelyx* is in the same predicament. If further information confirms this suspicion, it will probably be convenient to separate the *Thecodontosauria*, *Cetiosaurus*, and perhaps *Stenopelyx*, as a group of the Suchospondylia, distinct from the Ornithoscelida on the one hand, and the Crocodilia on the other, under the name of "Sauroscelida."

EXPLANATION OF PLATE XIX.

View of the palatine face of the posterior half of the skull in one Eusuchian and three Mesosuchian Crocodiles, showing the modifications in the form and position of the secondary posterior nares.

Fig. 1. *Steneosaurus Larteti.* (Deslongchamps, "Notes Paléontologiques," pl. xiv. fig. 2.)
2. *Metriorhynchus Blainvillii.* (Deslongchamps, ibid. pl. xx. fig. 1 *b*.)
3. The Crocodilian skull from the Wealden at Brook Point, in the Isle of Wight. Of the natural size.
4. *Gavialis gangeticus.* (D'Alton and Burmeister, 'Der fossile Gavial von Boll,' pl. iv. fig. 2.)

DISCUSSION.

Prof. DUNCAN said that it was impossible to criticise a paper of this kind, and that it would perhaps be a greater compliment to give a silent assent to the author's statements. At the same time he remarked that in teaching Indian geology he had been much struck by the homotaxis of the strata above the Indian Coal-bearing beds and those containing *Stagonolepis* in Scotland. In the Trias of India a Parasuchoid Crocodile was associated with *Hyperodapedon*, and a Dicynodont gave an African facies to the fauna. He thought the history of the evolution of the Crocodilia would have to be worked out in India, but remarked that none were known there between the Trias and the Sewalik deposits. He inquired of Prof. Huxley whether there was any alliance between *Stagonolepis* and *Parasuchus*, and what had been made out with respect to the structure and analogies of the latter genus. He considered that the case established by Prof. Huxley with regard to the Crocodiles furnished a stronger support to the hypothesis of evolution than even that of *Hipparion* and the Horse.

Mr. EVANS remarked that the paper was a most interesting and important contribution to the literature of evolution. Referring to the differences in the position of the nostrils, he suggested that it would be a great gain if these could be correlated with differences in the mode of life, as thus we should probably acquire some clue to the causes of the successive modifications of the type.

Prof. SEELEY saw no ground for doubting the value of Prof. Huxley's conclusions with regard to *Stagonolepis*, but thought it might be for the advantage of science to have other ways of looking at the evolution of the Crocodilia. He was not inclined to believe that the characters of the base of the skull, which Prof. Huxley had dwelt upon, afforded ground for a subdivision of the Crocodilian type—not only because he thought the character insufficient in itself among Reptiles, but because he did not believe that the characters of the older group were in any way Lacertilian. He spoke of the great range both of osteological character and vital organization in the existing Lacertilia, which rendered it difficult to know exactly to what the author specially referred; and he pointed out that the Lacertilians were surviving types from which *Stagonolepis* could not be supposed to have descended, unless the Lacertilian type had remained unchanged, and the Crocodilian type had alone been developed. Hence, seeing the numerous Lacertilian characters in the limbs of Chelonians, he inquired of the author whether he would not be disposed to consider the few Lacertian features of *Stagonolepis* as due to the conditions of existence rather than as resulting from descent.

Prof. HUXLEY, in reply, stated that the Indian Crocodile (*Parasuchus*) was very like *Belodon* in the jaw and teeth, the scapula and coracoid, the vertebræ, the ilium and the tibia. The tibia had the proximal end like that of a Lizard, the distal like that of a Crocodile. Additional remains from India furnish a new point of resemblance between the Indian deposits and those of Elgin. With regard to the difference in the position of the nostrils, he did not know that any reason could be given for this, unless the modification might facilitate respiration when the animal was engaged, after the manner of Crocodiles, in drowning its prey; but this would not hold good in the case of the Gavial, which feeds on fish. The food of *Stagonolepis* was doubtful: the teeth were often more or less ground down. In reply to Prof. Seeley, he stated that his comparisons were not founded on the skull alone, but on the other principal characters. As to the older Lacertilia, he had paid some attention to them, and considered that in all their essential characters they resembled the existing forms; the modern *Sphenodon* (or *Hatteria*) of New Zealand was singularly like the Triassic *Hyperodapedon.* The skull of *Belodon* has many curious resemblances to that of *Hatteria.* His conclusion was, that the existing Lacertilia were little modified, and the existing Crocodilia much modified, descendants from a common ancestral form of palæozoic age.

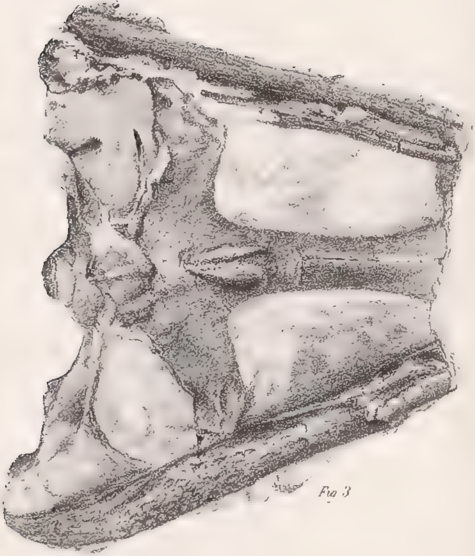

Fig 3

Fig 1

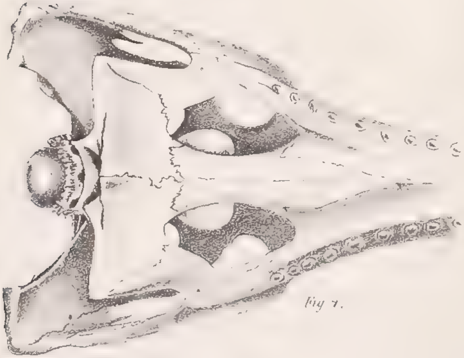

Fig 4.

Fig 2

G Sharman lith

M&N Hanhart, imp

[illegible] OF CROCODILIA

28. *On the* Maxillary Bone *of a* new Dinosaur (Priodontognathus Phillipsii), *contained in the Woodwardian Museum of the University of Cambridge.* By Harry Govier Seeley, Esq., F.L.S., F.G.S., Professor of Physical Geography in Bedford College, London. (Read March 24, 1875.)

[Plate XX.]

Among the few Reptilian fossils collected by the late Dr. Forbes-Young, and presented to the Woodwardian Museum of the University of Cambridge by Sir Charles Young and Henry Young, Esq., was a not very promising specimen showing tooth-sockets, imbedded in a yellow sandstone, containing a variety of *Pecten vagans*. It was in association with bones from the Wealden of Tilgate Forest, but may be of Great Oolite age; though I have collected a similar *Pecten* from a purple clay low down in the Wealden series at Lulworth. In 1869 the matrix of this fossil was removed, so as to expose the external aspect of the jaw; and as in those days I saw no reason for thinking it other than an Iguanodont maxillary bone, the species was briefly described in the 'Index to the Aves, Onithosauria and Reptilia in the Woodwardian Museum' (pp. xix. and 82) as *Iguanodon Phillipsii*. Mentioning to the Woodwardian Professor (Prof. Hughes) my desire to describe this and the other species which are briefly indicated in my published catalogues prepared for the late Prof. Sedgwick, Prof. Hughes met me with great cordiality, and afforded every assistance in examining the specimens. I offer my thanks to Prof. Hughes for this courtesy, which enables me to give effect to a request reiterated by Prof. Sedgwick during the last years of his life.

After cleaning the fossil a little, I found several successional teeth, which closely resembled the teeth of *Scelidosaurus* and the teeth attributed by Prof. Huxley to *Acanthopholis*; so that I have had no doubt of its claim to rank as a distinct genus under the name of *Priodontognathus*, and in nearer association with *Hylæosaurus* than with any Wealden type. The specimen is 4$\frac{7}{8}$ inches long, is compressed from side to side, and—since the palatal part of the bone, if it ever existed, is broken away and missing—consists principally of the external and alveolar portion, showing anteriorly its surface for vertical squamous sutural union with the premaxillary bone (Pl. XX. figs. 1–4, *a*), a narrow posterior spur for connexion with the malar bone (*b*), and an ascending nasal process in the middle of the upper margin (*c*), which divided the orbit from the narine. The alveolar part of the bone is 4$\frac{1}{4}$ inches long, an inch deep in front from the nasal to the alveolar margin, and rather narrower behind from the orbital region to the alveolar border. The bone terminates posteriorly in a narrow triangular claw-like process (*b*), which is prolonged outward away from the teeth, backward and somewhat downward, so as to increase the thickness of the bone to $\frac{3}{4}$ of an inch; this claw process is, as preserved, $\frac{5}{8}$ of an inch long, concave in length on the inside, compressed from above downward, so as to form a ridge in front, and seen from above downward narrows very slowly: it may be identified as the jugal process. Something similar in *Hypsilophodon* is represented by Prof. Huxley (Quart. Journ. Geol. Soc. vol. xxvi. pl. 1. fig. 1), and by Mr. Hulke (*ibid.* vol. xxx. pl. 3. fig. 1), though in that genus the process appears to be longer, stronger, and directed upward. This is a point of some importance, since in *Scelidosaurus* no such process is developed. Hence doubt is thrown on the value of Prof. Huxley's classification of the Dinosauria by their teeth; for while this genus by its teeth resembles the Scelidosauridæ, it is shown by this jugal process to have the temporal fossa and associated parts of the skull fashioned on the plan of the Iguanodontidæ (Quart. Journ. Geol. Soc. vol. xxvi. p. 34).

The maxillary bone, which is compressed from side to side, externally is gently convex in length, while internally it is rather more concave in length along the palatal border, so that the inner and outer sides are not quite parallel. The rather oblique line along which the horizontal palatal processes of the maxillary extended is inclined downward and backward; the inner surface of the bone between this line and the alveolar margin is concave in depth. Externally the bone is most convex from above downward, just in front of the jugal process, which is prolonged forward as a convex ridge, making the bone above it seem obliquely flattened and convex, and making the bone below it concave. But a little further forward the bone is steadily convex from above downward, and the convexity grows less till it is obscured in the ridges at the base of the nasal process. The external convexity causes the bone to terminate above and below in a sharp ridge.

Running along the lower external alveolar border of the bone, in the usual position of the dental foramina, is a series of unusually large perforations (see figs. 1 & 3), one corresponding to each tooth. They are larger than in the British-Museum specimen of *Teratosaurus*, or the maxillary of *Megalosaurus*, figured by Prof. Huxley (Quart. Journ. Geol. Soc. vol. xxv. pl. 12). The foramen above the last tooth is not preserved; the third foramen is an eighth of an inch from the palatal border, and displays a young successional tooth descending in the socket behind it. The foramina get larger from behind forward; and other teeth are seen behind the sixth, eighth, and eleventh; the twelfth is the largest foramen, resembling a tooth-socket ascending into the jaw. A minute foramen corresponds to the fourteenth socket; but the fifteenth, sixteenth, seventeenth, and eighteenth are in much thinner bone in front of the jaw, and have no corresponding foramina; the sockets of these anterior teeth are smaller than the others, so that they may have presented a difference from the others, like that seen in mammals between the premolar and molar teeth. It may be that, by those anterior teeth having already come down, the foramina corresponding to them have already been obliterated, owing to absorption of their lower borders; and it seems to me probable that the hinder foramina may have been similarly obliterated with age, the new teeth differing from the usual successional type of Reptiles by being on the outside instead of on the inside of the old tooth.

The tooth-sockets give no other indication of their existence externally; but on the inner side of the jaw are eighteen semiovate sockets, largest in the middle and becoming smaller towards the two ends (fig. 2). The last socket of all displays the basal attachment of a tooth to the socket, and shows the socket of the successional tooth in front of it. The sockets are separated from each other by narrow intervals of bone, indicating that the teeth were scarcely so crowded as in *Iguanodon*, but in this better resembled *Scelidosaurus*. No specimen shows the fang; but the crowns of the teeth are like those of *Echinodon*, *Scelidosaurus*, and *Acanthopholis*. The tooth is more compressed from within outward than in *Echinodon*, and differently implanted; while it appears to differ from that genus and from *Scelidosaurus* in not having large terminal lateral denticles; and the maxillary bone in the two has entirely dissimilar forms.

Of *Acanthopholis* no evidence of jaws is published except the teeth referred to that genus by Prof. Huxley (Geol. Mag. vol. iv. p. 65); but while I have no reason to doubt the excellence of that determination, it may be remembered that no similar teeth have been found in the Cambridge Upper Greensand, in which *Acanthopholis* is far from rare, and in which its jaws occur. On the other hand, no scutes similar to those of *Acanthopholis* are recorded from Wealden beds, or from the Great Oolite. The teeth of *Priodontognathus* resemble those figured by Prof. Huxley so well that the differences are chiefly limited to those of the present fossil being relatively narrower, having only from five to seven denticles on each serrated side of the crown, wanting the thickening at the base of the crown, terminating in a sharp point, and having a greater inflation in the median line of the tooth, more like that seen in *Echinodon* and *Scelidosaurus*. These small points, together with our ignorance of the facial characters of the Greensand and Chalk-marl fossil seem to me to suggest the desirability of the two types being located in separate genera. The only other genus which it resembles is *Hylæosaurus*; but of that genus also the maxillary bone is unknown; and the reference of the teeth named *Hylæosaurus* to that genus is so hypothetical that they may, with almost equal probability, be referred to any other genera of Wealden Dinosaurs of which the dentition is unknown. The crown, moreover, is of different form from that of this fossil; and though *Hylæosaurus* has lateral serrations, they are so fine and numerous as not to be a prominent character.

The maxillary bone terminates anteriorly in a nearly vertical smooth bevelled surface, which is from $\frac{1}{8}$ to $\frac{1}{4}$ inch wide, and looks forward and outward (figs. 1 & 3, *a*); against this surface the premaxillary bone abutted, much after the manner of many mammals and Lizards.

The superior limit of the maxillary bone in its anterior inch is parallel to the alveolar border; it is horizontal and somewhat expanded. Passing backward, this surface becomes concave in length by ascending a little way up the nasal process. It is divided by a remarkable longitudinal groove (which originates within half an inch of the anterior end of the bone) into two unequal parts (figs. 1 & 4, *e*). The larger inner part widens considerably in front, and is nearly enclosed a little further backward, where it terminates $1\frac{1}{8}$ inch from the palate and $1\frac{3}{4}$ inch from the anterior end of the bone in a smaller canal directed backward, upward, and outward.

The larger anterior groove appears to correspond with the infraorbital canal of the second division of the fifth nerve, which seems to reappear on the inner side of the bone and to be prolonged backward in a groove parallel to the alveolar border (fig. 2, *e*). The external border of the groove forms a strong oblique ridge, which ends behind in a tubercle.

The nasal or frontal process of the bone rises over the middle of the bone to a height of $1\frac{7}{8}$ inch from the alveolar border (figs. 1, 2, & 4, *c*). It is very thin, and extended posteriorly a little further than is indicated by its preservation; it is directed upward, backward, and a little outward; its front border is straight, entire, concave from before backward, and rounded from within outward, and looks obliquely upward and forward. The inner triangular or subtrapezoidal surface of the process is smooth, concave from above downward, and slightly concave from before backward. It forms $1\frac{1}{4}$ inch of the external border of a large anterior vacuity in the skull, which looked forward and upward, and was presumably the left narine. The outer side of the process is convex in length, with a slight oblique ridge running below its superior border, while below this ridge the process is convex from above downward.

The extraordinary form of this bone is no way paralleled in the maxillary bone of birds, and lends no manner of countenance to Prof. Huxley's morphological hypothesis of the Avian affinities of Dinosaurs. It differs from *Hypsilophodon*, as figured by Mr. Hulke and Prof. Huxley, in the remarkable extension of the bone anterior to the nasal process, and in forming the posterior narial wall, after the manner of Chelonians, Lizards, and many mammals. This process is, among reptiles, Lacertian; and is also closely paralleled in the maxillary bone of *Hatteria*, which develops a corresponding, though relatively thicker, malar process posteriorly, which is similarly directed backward and downward. *Hatteria* has a similar ascending nasal process, and similarly has conspicuous dental foramina, though they are differently placed. This close correspondence becomes the more important when we remember how close are the resemblances to *Hatteria* offered by some Dinosaurs in the base of the cranium (*Craterosaurus*), in the pterygoid and quadrate bones (*Scelidosaurus*), and other parts of the skull. So that we may be sure that in some Dinosaurs, at least, the predominant cranial affinities are Rhynchocephalian.

There are, however, interesting resemblances among mammals, even, to the form of this maxillary bone. Thus a similar external

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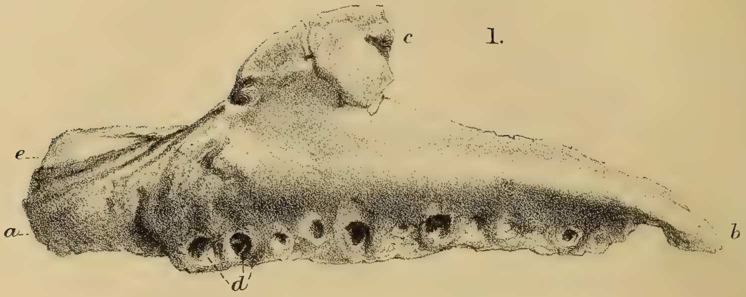

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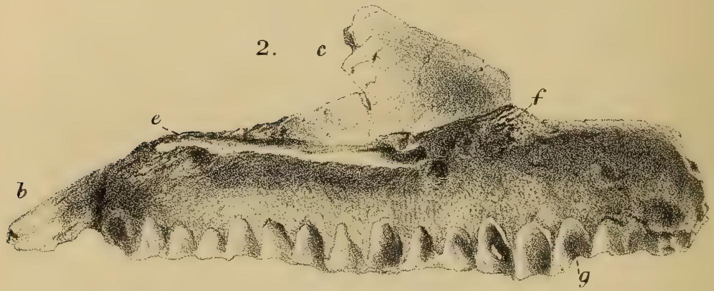

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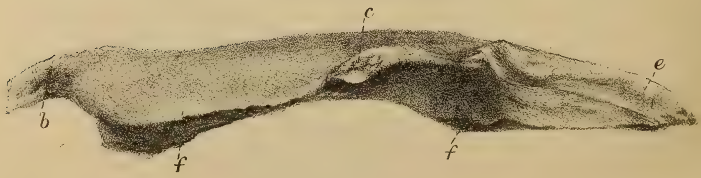

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G. H. Ford.

Mintern Bros. imp.

PRIODONTOGNATHUS.

shape is seen in the Rhinoceros, in which the premaxillary similarly joins a narrow anterior border of the maxillary, and the relations of the bone are such as might occur in a Dinosaur.

EXPLANATION OF PLATE XX.

Maxillary bone of *Priodontognathus*. Three fourths natural size.

Fig. 1. External aspect.
2. Internal aspect.
3. Alveolar aspect of the same bone, showing the tooth-sockets and the dental foramina.
4. Superior aspect of same bone, showing the semicircular outer nasal wall.

a, bevelled margin articulating with the premaxillary bone; *b*, posterior zygomatic process; *c*, ascending nasal process dividing the nostril in front from the orbit of the eye behind; *d*, dental foramina showing several successional teeth; *e*, canal for blood-vessel and nerve; *f*, fractured surface from which the palatal portion of the bone is broken away; *g*, sockets for the teeth; *h*, matrix.

DISCUSSION.

Mr. ETHERIDGE expressed his regret that the locality of this interesting fossil was unknown. The *Pecten* was not *P. vagans*, but *P. fibrosus*. He thought that the block containing the fossil was either Calcareous Grit or Coral Rag, and that it had probably been obtained as a fragment on the sea-shore. If so, it would be salt to the taste. In this case there were only two points from which it could have come, namely, the Yorkshire coast and Hastings.

Mr. JUDD remarked that Mr. Sorby had made a microscopic investigation of the structure of the Calcareous Grit of the Yorkshire coast, and suggested the possibility of ascertaining the locality from which this specimen had been derived by an examination of the microscopic characters of its matrix.

Mr. SEELEY, in reply, said that he did not detect the presence of salt in the stone. The *Pecten* probably was the form described as *P. fibrosus*: but he regarded *P. fibrosus* and *P. vagans* as identical.

29. DESCRIPTION *of a* NEW SPECIES *of the* GENUS HEMIPATAGUS, DESOR, *from the* TERTIARY ROCKS *of* VICTORIA, AUSTRALIA, *with* NOTES *on some* PREVIOUSLY DESCRIBED SPECIES *from* SOUTH AUSTRALIA. By ROBERT ETHERIDGE, Jun., Esq., F.G.S. (Read March 24, 1875.)

[PLATE XXI.]

THE Echinodermata of the Tertiary rocks of Southern Australia have not, as far as I am aware, yet received any systematic attention at the hands of palæontologists, although several interesting notices have from time to time appeared.

The Rev. Julian E. T. Woods figured*, but did not describe, a handsome Echinoderm from the Mount-Gambier beds of South Australia, under the name of *Spatangus Forbesii*. Mr. Woods pointed out that his species was identical with the *S. Hofmanni*, found at the Murray Cliffs by Captain Sturt†, and so identified by the latter, although it is not the *S. Hofmanni* of Goldfuss‡. In an interesting paper on some South-Australian Tertiary Corals§, Prof. P. M. Duncan described *S. Forbesii*, and referred it to Desor's genus *Hemipatagus*. He there notices its close similarity to *H.* (*Spatangus*) *Hofmanni*, Goldf., and its chief point of difference from the latter, in the presence of non-crenulated tubercles, which have a tendency to touch the scrobicular circle.

Dr. G. C. Laube|| has since redescribed *H. Forbesii*, W. and D., in addition to several other new forms from the Murray Cliffs, South Australia, apparently without having seen Prof. Duncan's paper.

Prof. M'Coy has named¶ several *Spatangi* from Victorian Tertiary rocks, which will be found in the accompanying synopsis I have appended below.

The form now brought under the notice of the Society, although closely allied to *H. Forbesii*, W. & D., at first sight, still possesses certain characters which have induced me to assign to it a new specific name, in the belief that it is undescribed. I obtained the specimens from a series of very ferruginous beds at Mordialloc, on the east shore of Port-Phillip Bay, Victoria. As a slight mark of appreciation of the efforts made by the Rev. Mr. Woods towards the advancement of palæontological and geological science in Australia, I would beg to propose that the species in question should be called *Hemipatagus Woodsii*.

Amongst a small collection of South-Australian fossils presented to the Museum of Practical Geology by Mr. H. F. Blanford, I was fortunate enough to meet with three of the new species described

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* Geological Obs. S. Australia, 1862, pp. 75, 83.

† Two Expeditions Int. S. Australia, ii. p. 254, pl. 3. fig. 10.

‡ Petrefacta Germaniæ, i. p. 152, t. 47. fig. 3, *a*, *b*, *c*.

§ Annals Nat. Hist. 1864, xiv. p. 165, pl. 6. fig. 3, *a*, *b*, *c*, *d*.

|| Sitz. d. K. Akad. d. Wissen. Wien, B. lix. Ab. 1, 1869, p. 193.

¶ Smyth's Progress Report, Geol. Mining Surv. Victoria, 1874, p. 36.

by Dr. Laube, in two instances exhibiting points of structure apparently not shown in his specimens.

Genus Hemipatagus, Desor.

Hemipatagus Woodsii, sp. nov. Plate XXI. figs. 1–7.

Sp. char. Cordiform, a little quadrangular; anterior end sulcated, rounded, or inclined to be a little truncate; posterior end truncate and considerably overhanging; sides sloping gently from the apical region. The test is highest immediately posterior to the apical disk, whence the summit is somewhat flattened to the edge of the nearly vertical anterior end. The ambulacra are broadly lanceolate, with blunt or abrupt apices; the anterior pair are widely divergent, and longer than the posterior, with their points somewhat curved outwards. The odd ambulacrum is placed in a deep groove, and only represented by minute equidistant round pores, which are lost before reaching the mouth; the sides of the groove in which the odd ambulacrum is placed are densely but minutely tuberculated. The ambulacral pores are deeply sunk, conjugate, and obliquely divergent; in the posterior pair of ambulacra there are from eight to ten pairs of pores in each series; the anterior series of pores of the anterior pair of ambulacra extend scarcely halfway from the apices of the ambulacra towards the apical disk; in each of the posterior series of the same ambulacra there are from eleven to thirteen pairs of pores. The whole of the interambulacral areas are densely and minutely tuberculated; the primary tubercles are large and few, and confined to the anterior pair, and to the extreme anterior portion of the lateral pair of interambulacra, and are surrounded by a deep scrobicula; the odd interambulacrum forms a somewhat obtuse angle. The apical disk is a little excentric, somewhat nearer the posterior end; the genital pores (*b*, fig. 5) are four in number, the posterior pair being wider apart than the anterior; the result of the intervention of a pyriform plate, which bears the madreporiform body (*a*, fig. 5). The anal orifice is oval, and situated in the concave and truncated posterior end (see fig. 4), which is bent inwards from below, giving to the termination of the odd interambulacrum a very overhanging or beak-like appearance (fig. 3). Below the anal orifice is a spectacle-shaped fasciole, carrying on each side a circlet of perforated primary tubercles, considerably smaller than those on the interambulacra; the anal plates are not preserved. The ventral or oral surface (fig. 2) is concave and divisible into three well-marked portions, two corresponding lateral parts strongly tuberculated, and a central portion comparatively smooth, in which is placed the mouth, and called by Prof. Duncan and Dr. Laube, in their descriptions of *H. Forbesii*, the "plastron." The tubercles of the lateral portions of the ventral surface are primary and perforated, nearly intermediate in size between those of the interambulacra and the subanal fasciole, but with one edge, that towards the anterior end, constantly in contact with the scrobicular circle (fig. 7). The "plastron" is narrowed anteriorly, but widens out posteriorly, where it is minutely granulated. The oral aperture is nearer the anterior end, transverse and semilunar, with the margin of the ventral lip a little thickened; in weathered specimens a few pores of the two pairs of ambulacra may be seen radiating from it.

Obs.—In two specimens before me the primary tubercles on the extreme anterior portion of the lateral pair of interambulacra are confined to two rows only, whilst in a third specimen one tubercle of the third row is developed, but the remainder are obsolete. The peculiar pyriform plate (*a*, fig. 5) separating the posterior pair of genital pores, corresponds to a similar plate well shown in an enlarged figure of the apical disk of *Spatangus purpureus*, Müll.[*] (*a*, fig. 9). It is there seen to be a prolongation backwards and an enlargement of the right antero-lateral genital plate, and therefore occupies a somewhat corresponding position to the Madreporiform body in some of the Endocyclica, although posterior to the apical disk instead of anterior.

Affinities and Differences.—From *H. Hofmanni*, Goldf.[†], our species, as in the case of *H. Forbesii*, W. & D., is distinguished by non-crenulate tubercles which, on the ventral surface of the test, unite with the scrobicular circle, and by the much more convex form. From *H. Forbesii*, W. & D., to which it bears the nearest resemblance, *H. Woodsii* is at once distinguished by the more convex form, straighter and more truncate anterior end, and much more overhanging posterior end, which slopes downwards more rapidly than in *H. Forbesii.* In the latter the whole of the dorsal surface is flattened and compressed, whereas in *H. Woodsii* it is merely that portion immediately anterior to the apical disk. In the last-named the primary tubercles are much less developed than in *H. Forbesii*, in which they extend further along the lateral pair of interambulacra than in the new species (see figs. 3 & 8), and, instead of being confined to two rows only, form three and sometimes four. From *H. grignoniensis*, Ag.[‡], the new species is distinguished by its greater dimensions, more convex form, and apparently a larger amount of tuberculation on the ventral surface; from *H. tuberculatus*, Zittel[§], by the same characters which separate it from *H. Forbesii*, W. & D.[||]. Lastly, from *H. prælongus*, Herklots[¶], our species is distinguished by the form in general, and the much smaller number of primary tubercles.

Locality and Geological Position.—The specimens of *Hemipatagus*

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[*] After Desor, 'Synopsis der Ech. Foss.' t. 44. fig. 1.

[†] Petr. Germ. i. p. 152, t. 47. fig. 3, *a*, *b*, *c*; Desor. 'Synopsis,' p. 416, t. 44. figs. 4, 5.

[‡] Desor. *l. c.* p. 416; Forbes, Quart. Jour. Geol. Soc. viii. 1852, p. 342, t. 18. fig. 7.

[§] Foss. Mollusk. u. Echin. aus Neu-Seeland, "Novara" Expd., Geol. Theil, B. i. 2. Ab. p. 63, t. 12. fig. 1.

[||] Both Dr. Zittel and Prof. Duncan remark on the very close similarity existing between *H. Forbesii*, W. & D., and *H. tuberculatus*, Zitt.; in fact, the former remarks that, except in size, there is scarcely any difference (*l. c.* p. 64).

[¶] Foss. de Java, Echinodermes, 1854, *Spatangus*, p. 11, pl. 2. fig. 6 (= *Hemipatagus*, Zittel, *l. c.* p. 63).

Woodsii were obtained from Tertiary beds on the east shore of Port-Phillip Bay, near the small township of Mordialloc. The deposit in question was mapped by Mr. A. R. C. Selwyn as of Pliocene age, and extends from the environs of Melbourne southwards along the bay to Frankston, enclosing within its boundaries the great Carrum Swamp. The section at the exact point where I obtained the specimens, when in company with my friend and former colleague, Mr. C. D'O. H. Aplin, is as follows, from above downwards:—

a. Bed of sandy loam, containing fragments of marine shells, at present living in the bay, continuous along the coast for some miles.
b. Thin bed of ironstone pebbles, well marked.
c. Bed of ferruginous sand, with interbedded ironstone bands, intersected by vertical "pipes," containing white sand and an aluminous (?) material.
d. Yellow sandstone, with a few ironstone bands, containing *Ostreæ*, *Mytili*, *Hemipatagus Woodsii*, and fragments of other shells.
e. A very thin band formed of the comminuted fragments of shells.
f. Yellow sandstone, containing pieces of impure limestone, with a few fossils, *H. Woodsii*, &c.
g. Bed of concretionary ironstone, forming the beach at high-water mark; the place of this is here and there taken by a band containing large shells in a tolerably good state of preservation.

Many years ago this portion of the colony to the south of Melbourne was examined by Mr. W. Blandowski, who gave in his report* a section of the beds at a point some distance to the south of Mordialloc, between Schnapper Point and Balcombe's Creek, where beds of a similar nature to those now treated of again occur. His section naturally differs a little from the one here given.

Genus PSAMMECHINUS, Agassiz.

PSAMMECHINUS WOODSI, Laube. Plate XXI. fig. 10.

P. Woodsi, Laube, Sitz. d. k. Akad. Wissenschaften, Wien, 1869, Band lix. Abth. 1, p. 185, fig. 1.

When he described this elegant little form, Dr. Laube does not appear to have possessed a specimen with a well-preserved apical disk. Fig. 10 is the outline of a specimen in the Blanford collection, showing the apical region. The genital plates are roughly triangular, with moderately large pores. The madreporiform body on the right antero-lateral genital plate is well marked and prominent. The perforations of the ocular plates are not visible; and the small plates covering the central aperture have disappeared.

Loc.—Banks of the Murray river; Blanford Collection, *M. P. G.*, one specimen.

Genus MICRASTER, Agassiz.

MICRASTER BREVISTELLA, Laube. Figs. 11 and 12, p. 448.

M. brevistella, Laube, *l. c.* p. 192, fig. 7.

A well-preserved specimen of this species is also in the collection, and clearly exhibits the ambulacral characters. Both the anterior

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* "Report to the Hon. Surveyor-General, on an Excursion to Frankston, Balcombe's Creek, Mount Martha, Port Phillip Heads, and Cape Shank," Trans. Phil. Inst. Victoria, i. p. 27.

and posterior pair are continued beyond the petaloid portions by separate pairs of impressed pores (fig. 11). The ventral grooves radiating from the mouth, and which correspond to the ambulacra on the dorsal surface, are distinctly pored, the posterior pair the least so, and the anterior pair the most so (fig. 12). The madreporiform body is badly preserved, but still may be seen occupying the centre of the apical disk.

Figs. 11 and 12.—*Micraster brevistella,* Laube.

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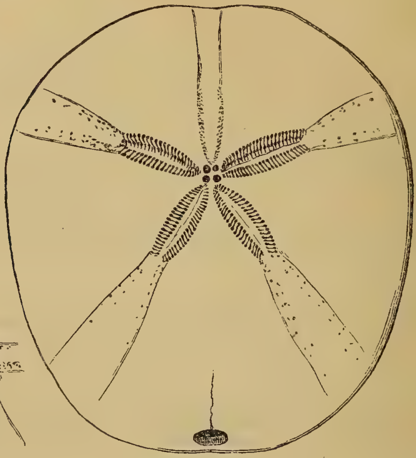

12

Fig. 11. *Micraster brevistella,* Laube, dorsal surface, showing ambulacral arrangement, nat. size. Banks of the Murray river, South Australia.
12. Oral aperture of the same, nat. size.

Loc.—Banks of the Murray river; Blanford Collection, *M. P. G.*, 1. specimen.

Genus Monostychia, Laube.

Monostychia australis, Laube.

M. australis, Laube, *l. c.* p. 190, fig. 3.

Clypeaster folium, Duncan (non Agassiz), Annals Nat. Hist. 1864, xiv. p. 166.

A comparison of the form referred to by Prof. Duncan as *C. folium,* in his paper on Australian Tertiary Corals, with Dr. Laube's description and figures of *M. australis,* has convinced me they are one and the same. For an opportunity of comparing the specimens I am indebted to the Council of the Geological Society.

Loc.—Mount Gambier, in the Coralline Limestone: *Coll. Geol. Soc. Lond.* Murray Cliffs: Jukes Collection, *M. P. G.*

I have to tender my best thanks to the Council of the Geological Society for the loan of specimens in the Society's collection; and to

my friends and colleagues Messrs. F. W. Rudler and C. R. Bone*, to the former for much assistance in the translation of Dr. Laube's paper, and to the latter for the very excellent and careful drawings which accompany these notes.

Appended is a synopsis of the Tertiary Echinodermata of Australia, so far as the various publications on the subject have come under my notice.

Genus CATOPYGUS, Agassiz.

C. elegans, Laube, *l. c.* p. 190, fig. 8; Murray Cliffs, South Australia.

Genus ECHINOLAMPAS, Gray.

E. corioensis, M'Coy (? M.S.) Smyth's Progress Report, Geol. Surv. Vict. 1874, p. 22; Port-Phillip Bay, Victoria.

E. ovulum, Laube, *l. c.* p. 191; Murray Cliffs, South Australia.

Genus EUPATAGUS, Agassiz.

E. Forbesii, M'Coy (M.S. ?) *l. c.* p. 22, Victoria.

E. murrayensis, Laube, *l. c.* p. 196. fig. 6; Murray Cliffs, South Australia.

E. Wrighti, Laube, *l. c.* p. 195, fig. 5. ? *Echinolampus*, sp. Woods, Geol. Obs. South Australia, 1862, p. 77, fig. 5; Murray Cliffs, and Mount Gambier, South Australia.

Genus HEMIPATAGUS, Desor.

H. Forbesii, Woods & Duncan. *Spatangus Hoffmanni*, Sturt (non Goldf.), Two Expds. Int. S. Aust. ii. p. 254, pl. 3. fig. 10. *S. Forbesii*, Woods, Geol. Obs. S. Aust. 1862, p. 75, &c. *Hemipatagus Forbesi*, Duncan, Annals Nat. Hist. 1864, xiv. p. 165, t. 6. fig. 3; Laube, *l. c.* p. 193, fig. 4; Murray Cliffs and Mount Gambier, South Australia.

Genus MICRASTER, Agassiz.

M. brevistella, Laube, *l. c.* p. 192, fig. 7; Murray Cliffs.

Genus MONOSTYCHIA, Laube.

M. australis, Laube, *l. c.* p. 190, fig. 3. ? *Clypeaster*, sp. Woods, Geol. Obs. S. Aust. 1862, p. 77; *C. folium*, Duncan (non Ag.) Annals Nat. Hist. 1864, xiv. p. 166; Murray Cliffs and Mount Gambier, South Australia.

Genus PARADOXECHINUS, Laube.

P. novus, Laube, *l. c.* p. 188, fig. 2; Murray Cliffs, South Australia.

Genus PSAMMECHINUS, Agassiz.

P. Woodsi, Laube, *l. c.* p. 185, fig. 1; Murray Cliffs.

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* Since this paper was written we have had to lament the loss of this talented artist.

Genus Scutella, Lamarck.

S. tamboensis, M'Coy (? M.S.) *l. c.* p. 22; Mount Tambo, Victoria.

In addition to the foregoing, species of the following genera have been indicated, viz.:—

Cardiaster, Woods, Geol. Obs. S. Aust. 1862, p. 77; Mount Gambier, South Australia.

Cidaris, Woods, Geol. Obs. S. Aust. 1862, pp. 76, 81; Mount Gambier, South Australia.

Echinus, Sturt, Two Expds. Int. S. Aust. ii. p. 254, pl. 3. fig. 11; Murray Cliffs, South Australia.

Schizaster, Duncan, Annals Nat. Hist. 1864, xiv. p. 168; Adelaide District, South Australia.

EXPLANATION OF PLATE XXI.

Fig. 1. *Hemipatagus Woodsii*, R. Etheridge, jun., dorsal surface, nat. size. Mordialloc, Victoria.
2. Ventral view of the same, nat. size.
3. Side view „ „ „
4. Anal „ „ „ „
5. Apical disk, considerably enlarged: *a*, madreporiform body; *b*, genital plates; *c*, ocular plates.
6. Primary tubercles on the interambulacral plates, enlarged.
7. Primary tubercles on the ventral surface, showing their union with the scrobicular circle, enlarged.
8. *Hemipatagus Forbesii*, Woods & Duncan, side view, nat. size. Mount Gambier, South Australia.
9. *Spatangus purpureus*, Müller, apical disk after Desor (Synopsis des Echinides, t. 44, f. 1).
10. *Psammechinus Woodsi*, Laube, outline drawing, showing the apical disk; 10 *a* shows the natural size. Banks of the Murray river, South Australia.

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1.

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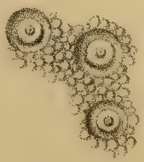

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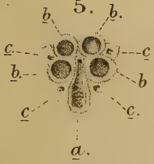

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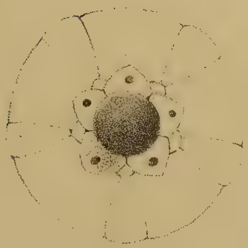

10a.

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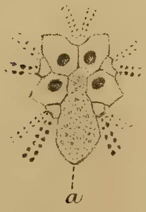

G.H.Ford.

Mintern Bros. imp.

AUSTRALIAN ECHINOIDEA.

30. *On some* NEWLY EXPOSED SECTIONS *of the* "WOOLWICH AND READING BEDS" *at* READING, BERKS. By Prof. T. RUPERT JONES, F.R.S., F.G.S., and C. COOPER KING, Esq., R.M.A., F.G.S. (Read February 24, 1875.)

[PLATE XXII.]

CONTENTS.

§ I. *Introduction.*—Coley Hill, in the south-western suburb of Reading, is composed of "Woolwich and Reading Beds," lying on Chalk. It is south of the similarly constituted Castle Hill, and divided from it by a small but deep valley, opening on the Kennet, which here runs from south to north at the eastern end of each of these little hills, and divides them from the high ground on which the Katesgrove Kiln is situated.

This last-mentioned locality was visited and described by Dr. Buckland in 1814 ("Catsgrove-Hill Brick-kilns," Trans. Geol. Soc. vol. v. p. 278), by Mr. Rolfe about 1833 (*ibid.* ser. 2, vol. v. p. 127), by Mr. Prestwich about 1852 (Quart. Journ. Geol. Soc. vol. x. p. 87), and in 1858 by the Geological Surveyors, who reported on it in 1861 and 1872 ('Memoirs Geol. Survey, Explan. Sheet 13,' 1861, p. 29, and vol. iv. 1872, p. 188). At the same time they surveyed Castle and Coley Hills* above mentioned (*ibid.* p. 39, and *ib.* p. 197). At none of these places in 1858 were exposures of the Lowest Reading Beds and the Chalk open to view.

Of late years, however, a greater local demand for lime has led to the excavation of Chalk at Coley Hill†; and since 1869 we have made repeated observations, as further sections of these Lowest Tertiary strata have been exposed at the pits on the north and south sides of the eastern end of the hill‡.

§ II. *The Bottom Bed.*—On the very even but perforated surface of the Chalk, noticed by Buckland, Rolfe, Prestwich, Whitaker, and others as occurring in Berks and Hertfordshire, the loamy and pebbly green sands§, constituting the "Bottom Bed" (Whitaker), were found to carry the usual abundance of Oyster-shells, with casts of

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* "David's Hill," Buckland, "St. David's Hill," Prestwich; *opp. citt.*

† We have been told that at the Castle-Kiln pit, now disused and partly built over, extensive underground excavations in the Chalk were formerly carried on.

‡ The north pit is worked by Mr. Collier, and the south pit by Mr. Wheeler.

§ Some seams in this part of the formation consist of brown clay traversed vertically and obliquely by irregular subcylindrical lumps of green sand, as if a mud had been channelled by animals (lobster-holes for instance), or perforated by stems and masses of sea-weeds, and the cavities so produced subsequently filled up with sand.

other Bivalves, also many Sharks' teeth, not of large size, and one fragment of a palate of *Myliobates* (Wheeler's pit). Carbonized woody matter was also observed in small quantities. Besides the green-stained unworn Chalk-flints characterizing this deposit, *pebbles* also of flint occur, and many sharp fragments of flint, which have nothing but the glaze of their surface and their position in the series to indicate antiquity. Possibly they were split off on shore by frost in cold seasons of the period. One small pebble of siliceous schist, another of quartzite, and small angular pieces of Chalk were also met with.

At one spot in the northern pit of Coley Hill Oyster-shells were absent; at all events, in the small area (about 4 feet square) of the trial-pit, shown by the lower part of Section No. 3 (Pl .XXII., plan of the pit, figs. 3 & 4). In the adjacent large Chalk-pit (Section No. 4, fig. 4), 35 yards to the east, there was clear evidence of the Oyster-bed, and indeed of its forming two layers.

In Mr. Wheeler's pit (marked "Coley Kiln" on the Ordnance Map) on the southern side of the hill, about 120 yards distant, the Oysters abound at the same horizon, but are not distinctly in two layers.

The *Ostreæ* are known to occur at Katesgrove, $\frac{1}{3}$ mile to the east, and at the railway-cutting, $\frac{1}{2}$ mile to the west, near the Bath Road; but they were not found by Mr. Whitaker at Castle Kiln, about 200 yards to the north ('Mem. Geol. Survey, Explan. Sheet 13,' pp. 24 and 39).

§ III. *The Blue Clays in the Buff Sand.*—As elsewhere, in neighbouring sections described by Prestwich and Whitaker, a blue shale occurs in Section No. 4, at about 12 feet above the Chalk. We recognized it at Collier's, Wheeler's, and Poulton's (Katesgrove) Pits as a laminated, tough, silty clay, with frequent patches of decomposed vegetable matter, and with black (manganese ?) infiltrations in its jointings.

In Section No. 4 a seam of lignitiferous bluish grey clay, 3 inches thick, traverses the yellow sand 3 feet 6 inches above the bluish shale above mentioned; and in Wheeler's pit, 118 yards distant, on the south side of the hill, there are three or more similar seams, curved, and varying in thickness and persistency, in a corresponding position among the false-bedded yellowish sands.

In Section No. 4 the lower band of shale has a full development of about 3 feet, with yellowish sand above and below; but at a distance of 35 yards to the W., and vertically above the spot where we noticed the absence of Oysters in the lowest beds, both this clay and the upper and thinner seam* are wanting, yellow sands, 26 feet thick, intervening between the "Bottom Bed" and the Mottled Clay

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* The leaf-bed, with which these blue shales correspond, has been found close by, on the north, at Castle Kiln (Whitaker, 'Geol. Surv. Mem.' vol. iv. p. 197), and half a mile to the west, at the railway-cutting near the Bath Road (Prestwich, Quart. Journ. Geol. Soc. vol. x. p. 88). It is also known to occur at Shaw Hill, near Newbury, 13 miles distant. Mr. Rickman found that some of the "Woolwich Beds" near Dulwich abound with leaves (Mem. Geol. Surv. vol. iv. p. 131).

above. Nor was the blue clay noticed by Mr. Whitaker at the Castle Kiln above mentioned.

In the yellow sands of Sections Nos. 3 and 2 (Pl. XXII. fig. 4), however, on the same horizon as that of the plant-bearing clays in Section No. 4, some irregular thin seams of bluish tough clay with numerous scattered blue *clay-galls*, at least one subangular green-coated flint, and some lines of broken lignite appear to take the place of the discontinued strata; and in another section (No. 1) 24 yards to the west of Section No. 2, and 69 yards W. of No. 4, there were still no indications of the missing clay-beds, except a thin seam of grey clay and clay-galls, with a pebble of black siliceous schist, or lydite, and some subangular grey Chalk-flints. This seam is similar in relative position and appearance to that in Section No. 2; but it is at a somewhat higher level, owing to its eastward dip of about 3°.

At Section No. 6, facing north, in a corner of the pit and 70 yards north of Section No. 1, some thin seams of clay and clay-galls come up in the sands (which are here lighter in colour) to within 5 feet of the surface, and, by their relative position and easterly dip, are evidently connected with the set of similar seams in Sections Nos. 1 and 2. In Section No. 6, however, the sands are disturbed by a fault, and some Mottled Clay is let down. The buff and grey sands come in again on the other side, Section No. 7, in fig. 4.

In Section No. 5 the Buff Sands lying below the Mottled Clay and on the grey shale have a local feature of considerable interest. Just where they happened to be attenuated by the slope of the valley, namely for the 25 yards between the disappearance of the Mottled Clay above and the exposure of the grey shale beneath, they contain numerous clay-galls of large size, some 18 inches in diameter. Some are mottled, and the majority are grey in colour; but many are ferruginous and hard from change, and somewhat septarian. Ferruginous nodules of a similar nature occur, in far less abundance, in the same sand (but greenish) in Wheeler's pit, on the south side of the hill*. In Collier's pit some of the galls above mentioned consist of grey sandy clay; others of tough, light-brown clay with some sand; and others of dense dark-brown clay. They often contain chalk-flints, rolled and subangular, of various sizes, with flint, grit, and quartz sand. Some of the lowest of these nodules, nearest to the shale below, are much changed, consisting only of limonite crusts and ochreous cores. These nodules occur in large numbers in the excavations over the blue shale for at least 45 yards beyond the eastern margin of the pit; and one at least was found low down in the grey and buff sands of Section No. 6, on the same horizon, 100 yards distant to the west.

The false-bedded quartzose sands, in which both the above-mentioned regular shales and the derived clays and clay-galls occur, vary from white and grey to buff and ochreous in these sections, as elsewhere; and their surface has a slope of nearly 5° to the S.E. by E. (magnetic), almost reaching the top of the ground in Section No. 6,

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* The ochreous nodules, yielding an excellent pigment, referred to by Mr. Rolfe, *op. cit.* p. 127, are probably the same as these.

but about 18 feet below it in Section No. 4, where they are seen to have a thickness of little more than 18 feet, while they are nearly 30 feet thick in Section No 6, 72 yards to the W. They therefore suffered considerable denudation eastward before the Mottled Clay was laid upon them. They show a greater thickness in this locality* than in any other Section in the neighbourhood. The same thickness of "Reading Tertiaries," however, as a whole 47′ 6″, has been measured at Katesgrove†; but they have much more frequent alternations of sands and clays, as observed by Dr. Buckland ('Mem. Geol. Surv.' vol. iv. p. 188).

§ IV. *The Mottled Clays.*—The Mottled Clays overlying the Buff Sands just described, and having the same dip, thicken towards the east (in the direction the Sands below thin away) not only in Collier's pit, but in Wheeler's, on the other side of the hill; and over the valley beyond, at Katesgrove, as is well known, the "Basement Bed" of the London Clay sets in upon them (Mem. Geol. Surv. vol. iv. p. 188). On the north side of Coley Hill, not only does the westerly thinning-out of the "Mottled Clays (Sections Nos. 1 & 6) deprive the occupier of much plastic material‡, but a small E.-W. fault at the S.W. corner of the pit still further deteriorates the clay by disturbing and muddling it with the superficial gravel; and the little E.-W. fault at the N.W. corner (Section No. 6) does not let down the clay in sufficient quantity for working.

In Section No. 5, both the gravel and the Mottled Clay, which shows a slight dip to the S.S.E., thin out on the southern slope of the valley dividing Coley Hill from Castle Hill. The softening of the clay on the slope has given it the appearance of bent laminæ hanging over towards the valley.

§ V. *The Superficial Gravel.*—In Coley Hill red loamy gravel, chiefly of flint, with some quartz, quartzite, &c., overlies the Mottled Clay along a horizontal surface, which, however, has been cut into by the existing valleys. The gravel averages 5 feet in thickness, but is pocketed in the eroded surface of the clay; and the process of clearing it off, in baring the clay and freeing it from stones, leaves very numerous, close-set, funnel-shaped pits, varying in size, but often nearly 2 feet deep, and 2 or 3 feet across. At both faults, one at the S.W. and the other at the N.W. corner of Collier's pit, the gravel is deeper.

§ VI. *Theoretical Conclusions.*—In conclusion, we wish to draw

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* See also Buckland quoted by Prestwich, Quart. Journ. Geol. Soc. x. pp. 87, 88.

† Only 38 feet of the Reading beds, from the Chalk upwards, were seen at the Railway-cutting, and 33 feet at Castle Kiln. At Shew Hill, near Newbury, Mr. Prestwich measured 52 feet of these strata, the Mottled Clay being 26 feet thick, and having only one seam of sand in it. Many other sections (Sonning, &c.) may be compared in Mr. Prestwich's paper, and in the 'Mem. Geol. Surv.' vol. iv. The irregularity of deposition in the "Reading Beds" has been fully noticed by Buckland, Prestwich, and Whitaker, and is evident in all the Sections; but in this paper attention is especially directed to the evidences of denudation and reconstruction.

‡ At first he supposed that it lay equally over the property.

attention, not only to the excellent sections at present exposed, but more particularly—1st. To the local absence of Oyster-shells (in Section No. 3) within 40 paces of a rich portion of the old Oyster-bed, and in a deposit similar to and continuous with the loamy green sand full of Oysters. This barren margin of the Oyster-bank may have been infested by some material or agent inimical to life, though the borers which perforated the underlying sea-bed of Chalk had existed previously in abundance. 2ndly. The absence of the leaf-bearing clay-beds in the yellow sands of Sections Nos. 3, 2, 1, & 6. The seam of lignitiferous clay, 3 inches thick, and the tough blue shale, nearly 3 feet thick, must terminate within a very few yards west of Section No. 4; whether by the dying-out of lenticular deposits, or by thinning or truncation due to erosion, is not clear, the section being there obscured. We think that the latter condition probably exists, as shown by the apparently drifted materials, such as clay-galls and varying seams of clay and lignite fragments, in Sections No. 2, No. 1, & No. 6.

In this case we regard the yellow sands of Sections Nos. 3, 2, 1, and 6 as having been rearranged in a kind of "Horse-fault," after an earlier deposition of strata, comprehending a westward continuation of the grey shales. These were removed by currents eating away a bank, or forming a channel, where the shale had existed, and leaving some remnants of its material, rolled and scattered in the present beds (see plan of the current in an estuary, and formation of shoals at the expense of older beds, Pl. XXII. fig. 1).

Such a circumstance, common enough in both old and recent formations, supplies one more fact in the history of these very interesting "Reading Tertiaries;" and if the actual line of this eroding current can be found by further observation, when Wheeler's Pit is cut back westward in a line with Sections Nos. 4 & 3, and compared with the tide- or stream-currents which may be made out of the false-bedded sands by application of Mr. Sorby's formula of "Drift-currents," so much the more will be known of the hydrography of the Early Tertiary Period.

The hypothetical current, causing the presumed Horse-fault, may have existed, though not with so much force, previously, whilst the Oyster-bed was being formed, and may have interrupted the deposition of Oyster-spat and the growth of Oysters in the area opened by Section No. 3.

3rdly. The history of the larger clay-galls, above the blue shale, in the yellow sands of Section No. 5. The excavation of the existing valley, and the absence of sections in Castle Hill make it impossible to trace these large clay-galls to any source on the north or north-east. It may be that they were derived from the destruction of part of the smaller and higher of the two leaf-beds seen *in place* in Section No. 4—or from a small cliff cut in a thicker portion of the grey shale itself (see fig. 2, showing the supposed destruction of the clay band), and that they lie in sand laid down on a flat surface denuded out of this clay-bed.

We have already suggested that this same grey clay was cut into further west. This would probably be at about the same time; and beyond Section No. 4 it was removed entirely, nothing being left but small seams of clay and clay-galls in the yellow sands, as seen in Sections Nos. 2, 1, and 6. We cannot suggest any more definite direction for the cliff or bank, than that possibly it was about N.–S. in accordance with the position of the apparently abrupt ending of the grey clays, between Sections Nos. 4 and 3: see the Plan of the Pit, fig. 3. This line would also agree with the local absence of Oysters at Section No. 3, and at Castle Kiln.

It is possible that there then existed other and distinct clay-beds, some even as dense and homogeneous as the present "Mottled Clay," of which some of these rounded lumps are the sole remnants. This goes to prove the greater complication of processes in the formation of the "Reading Tertiaries," and adds to the length of time required for them. In any case, not only does the rolling of the clay-galls bespeak a flat shore and neighbouring cliff, but their *enclosed flints* clearly indicate a beach, bank, or shoal of flint débris at no great distance, whether in fresh, brackish, or salt water*. In a section at Red Hill, 7½ miles W. of Reading, Mr. Prestwich (*op. cit.* p. 87) observed a "patch of angular chalk fragments, subangular flints, and flint pebbles" just above the yellow sands; and these, though rather higher in the series, were probably derived from a similar, if not the same, beach or shoal.

The scattered subangular flints and the occasional pebbles of lydite in the other derivative seams of clay and clay-galls, at a lower level, have also their own significance; and the green-coated flint in Section No. 2 shows that the "Bottom-bed" itself, or the nearly contemporaneous "Thanet Sand," was somewhere already exposed to denudation while the shallow-water and false-bedded yellow sands were being deposited.

EXPLANATION OF PLATE XXII.

Illustrative of Sections of the "Woolwich and Reading" Tertiary Beds at Coley Hill, Reading, Berks.

Fig. 1. Diagram of a river eating away its banks and forming shoals.

2. Diagram of the destruction of a clay bank, and the deposition of rolled lumps of clays, at two successive periods.

3. Diagrammatic plan of Collier's Pit, Coley Hill, showing the relative

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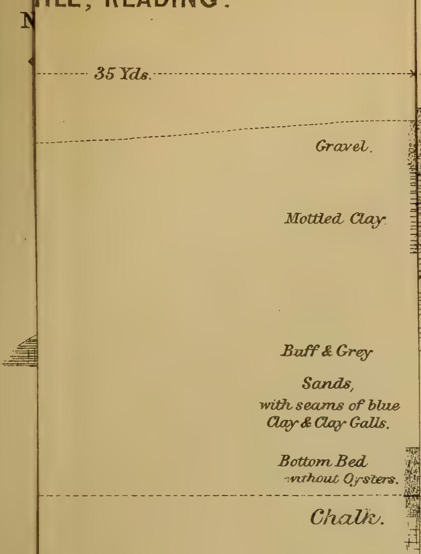
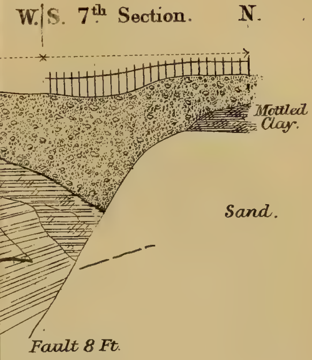
* As to the conditions of deposit, we see that the *Marine* "Bottom-bed" was succeeded by the shallow-water, perhaps estuarine, sands, and leaf-beds (some shell-beds with *Ostrea* hold this position in the London district), and these by the Mottled Clay, deposited, quickly perhaps, over a large area of quiet water invaded by mud inimical to life. To this area the sea, again, brought Oysters, as shown by the Shell-beds with *Cerithium*, *Cyrena*, and *Ostrea*, lying on the Plastic Clay at Guildford, 20 miles to the S.E., and at Croydon, nearly 40 miles to the E. by S. of Reading. These estuarine Oyster-beds, together with the marine Oldhaven series, if they existed here, were denuded off the clay in the Reading district before the Basement-bed of the London Clay was laid down. See also W. Whitaker "On the Lower London Tertiaries," Quart. Journ. Geol. Soc. vol. xxii. p. 409, pl. 22; and for the extension of these beds into France, &c., Prestwich, *ibid.* vol. xi. p. 213 &c., pl. 8.

ILL, READING.



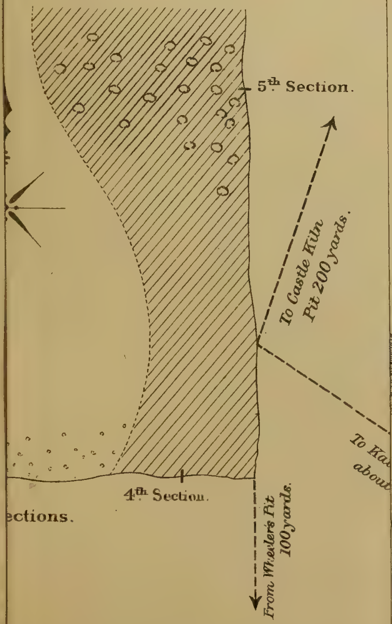


G. 3.

of Colliers Pit.

rt shows extent of the

Clay Galls.



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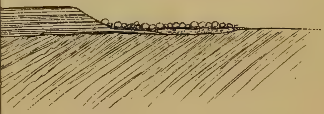


FIG. 4. SECTIONS AT COLEY HILL, READING.

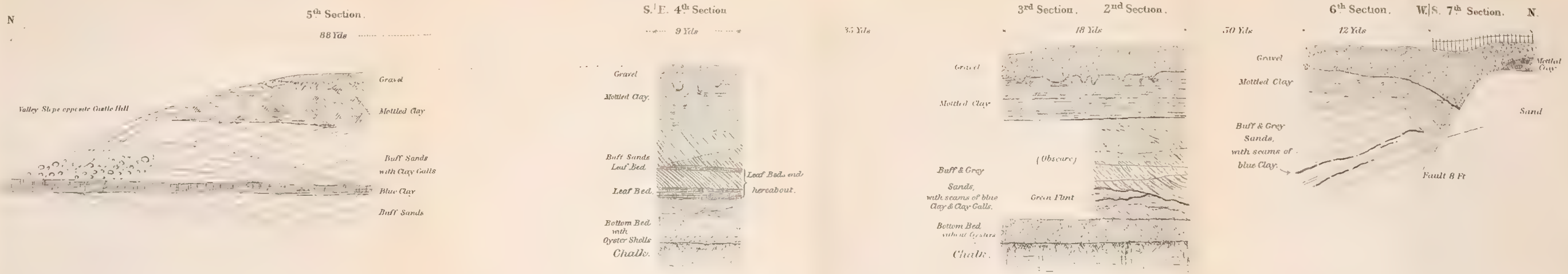


FIG. 3.

General Plan of Colliers Pit.
Note The shaded part shows extent of the Leaf Bed & Clay Galls

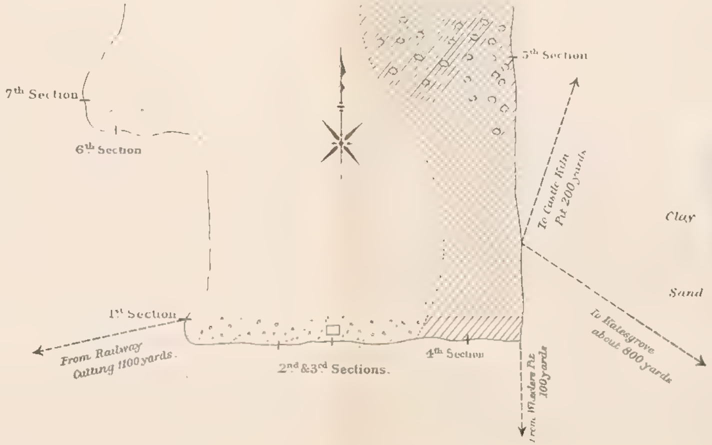


FIG. 1.

Formation of Shoals.

FIG. 2.

Destruction of Clay Bank & Deposition of Clay Galls

C.C. King

Dangerfield lith. 22 Bedford St Covent Garden

position of the seven sections, the extent of the blue shale, or leaf-bed, together with that of the lower series of clay-galls (small) in the sands, and of the higher (larger) rolled lumps of clay on the bed of shale.

Fig. 4. Sections Nos. 5, 4, 3, 2, 6, & 7 in their order.
Nos. 6 & 7 here take the place of Section No. 1.

Discussion.

Mr. Whitaker said that this careful noting of local features in such very varying sections was of great value, and hoped that geologists would continue to study the sections near Reading. The occurrence of clay-galls, or rolled pieces of clay, was interesting; some of them were, he thought, certainly derived from the destruction of previously existing beds; but others may possibly have been only isolated patches of some attenuated clay bands. Good examples of rolled clay may be seen on any clay shore, as at Sheppey and elsewhere.

Prof. Seeley stated that he had noticed the lumps of rolled clay at Reading, and that he had seen similar balls of clay derived from the Kimmeridge Clay in the marine gravel at Hunstanton. With regard to the "bottom-bed," he was inclined to believe that it constitutes an abnormal form of the Thanet Sands, being composed of quartz-sand, whilst the sands of the upper beds are mainly derived from flint.

Mr. Evans remarked that the denudation and reconstruction of beds seemed to be due to alterations of level. It was more surprising, at first sight, that the Oyster-beds, with their accompanying overlying strata, could be traced over areas so wide apart, than that even many local denudations and reconstructions should be observable. Still these latter furnished important evidence as to the history of the deposits.

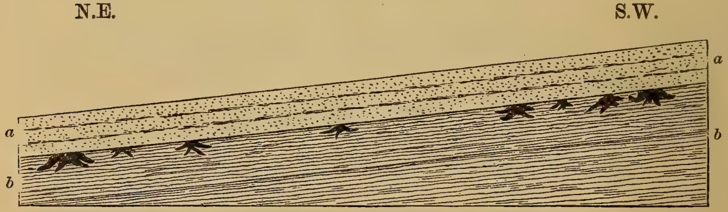
Prof. Rupert Jones explained that the large clay-galls, with and without enclosed flints, in the sand over the blue clay, lay about in great numbers, having been exposed and left by the workmen in moving the sand last summer. In the case of the smaller clay-galls at a lower level, the associated drifted flints, lydite and lignite, supported the idea of their having also been derived from other beds.

31. *On the* Remains *of a* Fossil Forest *in the* Coal-measures *at* Wadsley, *near* Sheffield. By H. C. Sorby, Esq., F.R.S., F.G.S., Pres. R.M.S. (Read April 28, 1875.)

In order to make the ground at the back of the South-Yorkshire County Lunatic Asylum more level, a considerable amount of coal-measure sandstone and shale was excavated in the autumn of 1873; and this exposed to view a number of the stumps of large fossil trees. My attention was called to them by my friend, Mr. W. P. Milner, one of the visiting magistrates; and soon afterwards I attended a meeting of the Visitors at the asylum, and pointed out on the spot the desirability of preserving some of the larger and better specimens *in situ*, so that their position and relation to the strata might always be seen. It was then at once resolved that two small sheds should be erected to protect the trees from the weather; and I am glad to say that this has been carried out in a most satisfactory manner. They have been made of wood, with felt roofs; and they have a number of glazed windows, so that the fossils can be easily seen, even from the outside, or more completely examined by procuring the keys at the Asylum. We may thus hope that these interesting remains will be preserved in a satisfactory state for many years to come.

The manner in which they occur is so similar to what has been described by Bowman*, Binney†, Beckett‡, and others, that I need not occupy the space of our Journal in repeating what has been already published, but may say that the facts bear out extremely well the views enunciated by Bowman, and seem to show that the trees grew in what is now a bed of earthy, clay-like shale, and then died and decomposed down to the level of the surrounding mud, leaving hollow stumps, subsequently filled with the sand now constituting the superjacent bed of sandstone (fig. 1). Both this and

Fig. 1.—*Section showing the position of the stumps in the Fossil Forest at Wadsley near Sheffield.* (Scale 1 inch to 40 feet.)



a. Sandstone. *b.* Clay-like shale.

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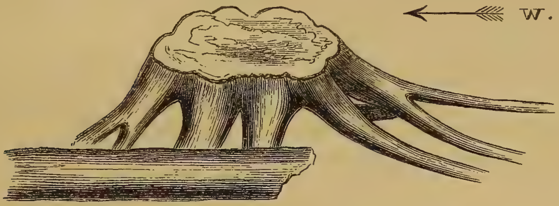
* Ed. New Phil. Journ. 1841, vol. xxxi. p. 154.

† Phil. Mag. 1844, xxiv. p. 165.

‡ Quart. Journ. Geol. Soc. vol. i. p. 41.

the subjacent clay-like shale are not of a nature suitable for the preservation of minute markings; and it is only just possible so to recognize the Sigillarian character of the trunks and the Stigmarian markings on the roots as to feel certain that they are *Sigillariæ.* Their general characters will be seen from the following drawing of the largest and best-preserved specimen (fig. 2). It is about 5 feet 2 inches in diameter, with almost as flat a surface as if it had been cut off with a saw. There are eight large roots, which when exposed are seen to bifurcate and extend in some directions for about 6 feet, after which they are either hidden or have been destroyed, so that their total length is unknown. By the side of this stump is a large prostrate trunk, as shown in the figure. These specimens are enclosed in one of the sheds. The total number of stumps which were exposed was about ten, spread over a distance of 40 or 50 yards. All that can be properly seen have either eight roots when the stump is large, or only four when small and partially grown, which agrees with what has been previously observed in similar cases. Two fine specimens occurring near together have been covered by a single larger shed.

Fig. 2.—*Fossil Stump of* Sigillaria *at Wadsley near Sheffield.*
(Scale $\frac{1}{5}$ inch to 1 foot.)



What appears to me to be one of the most interesting facts connected with these trees is the evidence they furnish with respect to the direction of the prevailing winds at the time when they grew. A careful examination of the trees now growing on the exposed moorland hills of the district shows that when they are young the prevailing westerly gales often make them incline towards the east; and in doing this, the roots on the west side are pulled straight and made to run more horizontally, whilst those on the east side are pressed down and made more nearly vertical; and these characters remain permanently when the tree has grown to a large size. Now this sort of difference on different sides can be recognized more or less decidedly in the case of all the stumps seen in the Wadsley fossil forest, but is especially well marked in the largest and best-preserved specimen (fig. 2); and it appears to me a very interesting fact that the direction of the prevailing high winds at the Carboniferous period thus indicated is almost exactly the same as that at the present period, as shown by the same facts seen in trees now growing in the neighbourhood.

Discussion.

Mr. Moggridge inquired whether the trees were rooted in solid rock or in earth. Near Swansea trunks of trees were imbedded in solid rock and upright.

Mr. Grantham inquired whether the trees were broken short off, leaving rugged tops, and whether any trunks were found.

Prof. Seeley said that in the Fens we find erect stumps of Yew, Oak, and Pine, and that the stumps never rise above the surface of the peat. Sometimes a bed of marine clay overlies the peat, and fragments of the trunks are found scattered in it, showing that the trees stood in the sea and died there.

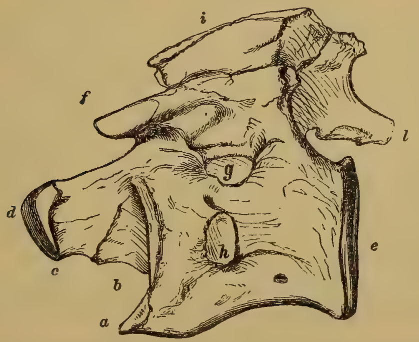
Mr. Sorby said that the lower parts of the roots are in soft clay shale, and the upper portions in hard sandstone. He thought that the trees were submerged, and that their trunks decayed down to the level of the water, the surface of the stumps being remarkably level, as though cut off with a saw.

32. *On the* Axis *of a* Dinosaur *from the* Wealden *of* Brook *in the* Isle of Wight, *probably referable to the* Iguanodon. By Harry Govier Seeley, Esq., F.L.S., F.G.S., Professor of Physical Geography in Bedford College, London. (Read May 26, 1876.)

This vertebra was collected for the Woodwardian Museum of the University of Cambridge by Mr. Henry Keeping, and catalogued in my 'Index to the Aves, Ornithosauria, and Reptilia' (p. 81) as the axis of a Dinosaur. The specimen is perfect, and but very slightly crushed from side to side. It measures $3\frac{1}{2}$ inches in length, from the termination of the dentata to the posterior articular face of the centrum. The vertebra has a small neural arch, and measures $3\frac{1}{4}$ inches from the base of the centrum to the top of the neural spine.

The centrum is depressed, and anteriorly measures $1\frac{5}{8}$ inch deep from the neural canal to the base, and is $2\frac{1}{2}$ inches wide over the articular surface. This surface, below the dentata, is nearly vertical (fig. 1, *a*), and forms more than a quarter of a circle (fig. 2, *a*). In the middle of the base of the centrum a wedge-bone ossification is anchylosed, as in birds (fig. 2, *a*), and projects forward for about a quarter of an inch. The vertical articular surface has its superior (or interior) outline nearly parallel to the circumference of the bone (fig. 2), and is rather more than $\frac{3}{4}$ inch deep. Confluent with this area, and between it and the underside of the dentata, which it occupies for half an inch, is an articular band margined by a somewhat sinuous anterior border (fig. 1, *b*), which is $\frac{1}{2}$ inch wide in the

Fig. 1.—*Axis of a Dinosaur from the Wealden of Brook.*
(Side view. Half natural size.)

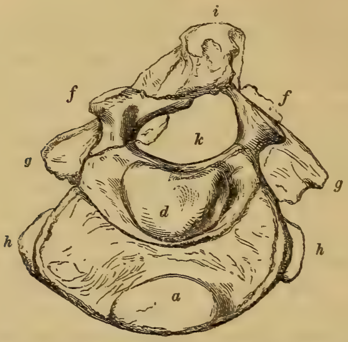


a. Anterior articular surface. *b.* Articular band. *c.* Non-articular surface. *d.* Dentata. *e.* Posterior articular surface. *f.* Anterior zygapophysis. *g.* Diapophysis. *h.* Parapophysis. *i.* Neural ridge. *l.* Posterior zygapophysis.

middle, but becomes narrower at its two extremities, which are $1\frac{1}{4}$ inch apart.

The dentata (figs. 1 and 2, *d*) projects anteriorly beyond the vertical articular surface for $1\frac{3}{8}$ inch, and apparently for $\frac{7}{8}$ inch in front of the articular surface for the atlas. The end of the dentata is an articular surface, semicircular, being convex below and flattened above; but it is scarcely rounded enough to be a quarter of a sphere, and has a slight depression in the middle. It is $1\frac{1}{8}$ inch broad, and appears to have joined the basioccipital bone as in birds; it is margined below by a prominent border, between which and the articulation for the atlas is the non-articular surface (fig. 1, *c*), concave from front to back, $\frac{3}{8}$ inch wide on the middle of the underside, and widening laterally to $\frac{3}{4}$ inch at the sides, which converge anteriorly towards the median line of the neural canal. The upper surface of the dentata is slightly concave.

Fig. 2.—*Axis of a Dinosaur from the Wealden of Brook.* (Front view. Half natural size.)



a. Wedge-bone articulation. *k.* Neural canal. The other letters as in fig. 1.

The neural canal (fig. 2, *k*) is large, concave from side to side, and behind the dentata forms a shallow cup-like depression, at the bottom of which are two nutritive foramina: a few other small foramina occur on the neural surface near the anterior termination of the dentata.

The posterior articular surface of the vertebra (fig. 1, *e*) is transversely elliptical; it is concave in the middle and slightly flattened above. The concave depression is slightly roughened, and resembles that seen in a Plesiosaurian vertebra; only the deepest part, instead of being a point, is a short transverse line. The surface is $2\frac{1}{8}$ inches broad, and $1\frac{1}{2}$ inch deep. Its outer and inferior margin is slightly convex; and below and just behind this convexity runs a sharp slightly elevated border.

The lengths of the centrum between the anterior and posterior articular surfaces are $2\frac{1}{8}$ inches at the sides, and $2\frac{3}{8}$ inches in the median basal line (fig. 1). The under surface of the centrum is expanded anteriorly, being widened from side to side by the parapophyses (figs. 1 and 2, *h*), which are large tubercles terminating in flat, vertical, ovate, lateral surfaces, which look backward and outward; each measures $\frac{5}{8}$ inch high and $\frac{3}{8}$ inch wide, and is placed below the middle of the side of the centrum, and about $\frac{1}{2}$ inch behind the anterior articular surface; the transverse width of the vertebra through the parapophyses is nearly 3 inches. Behind the parapophyses the centrum has a constricted, aspect measuring $1\frac{5}{8}$ inch from side to side at $\frac{3}{4}$ inch from the posterior end; in this line are two small foramina about an inch apart. The under surface has a slight median ridge, which does not extend forward to the wedge-bone; on each side of this the bone is flattened and a little convex from below upward, except under the parapophyses, where it is concave. A channel $\frac{3}{4}$ inch wide separates the parapophysis from the diapophysis. Above this channel is a prominent strong tubercle projecting transversely from the side of the neural arch. This second articulation for the rib (*g*) is flat, nearly circular, with a slightly elevated border; it looks outward, downward, and very slightly backward; and more than half its diameter lies behind the parapophysis, which it slightly overhangs.

The side of the neural arch is transversely oblong (fig. 1), concave in length and concave from above downward. In front, above the neural canal, it is compressed from side to side so as to form a prominent broad longitudinal ridge (*i*) rather than a neural spine. It is $\frac{3}{4}$ inch wide in front, narrower in the middle, and widens again behind; it is slightly convex in length, nearly horizontal, and less than 2 inches long.

On the middle of the side of the neural arch, on the same level with the top of the diapophysis, but in front of it and separated from it by a concave notch, is the small, thin, diverging, anterior zygapophysis (figs. 1 and 2, *f*), which is directed forward, outward, and downward. The anterior zygapophyses measure about 2 inches from side to side; and below them the bone is slightly compressed (fig. 2). The distance from the anterior to the posterior zygapophyses measures $2\frac{3}{4}$ inches, while the space between the anterior and posterior vertebral notches for the intervertebral nerves measures $1\frac{1}{2}$ inch in length.

The posterior zygapophysis is large and projects backward (fig. 1, *l*), is convex from side to side, and looks downward and a little outward; it projects nearly $\frac{1}{2}$ inch behind the neural arch, and measures $\frac{3}{4}$ inch in length and in breadth. The neural arch is excavated above and between the posterior zygapophyses; and the neural canal appears to be larger behind than in front.

This vertebra presents considerable resemblance in front to the axis of a bird, in the whole form and character of the articular surfaces of the zygapophyses, centrum, and dentata, in having a hypapophysial wedge-bone (although it is much smaller than in birds), and in the absence of a neural spine. Moreover, in those young birds in which the cervical rib is not yet blended with the vertebra there are two lateral articular surfaces wider apart, but not entirely incomparable with the articulations in the Dinosaur. The resemblance is almost as close to the axis of *Hatteria,* though in that genus the neural spine is large, and there are no lateral articulations for a cervical rib, a resemblance the more important since this ordinal type links itself closely with the Chelonia and Crocodilia. In the Crocodile the axis has a two-headed rib, but the odontoid process is not anchylosed to its flat anterior face, while its posterior face is as unlike that of the Dinosaur as is the corresponding surface of the axis in a bird. Among mammals the nearest resemblance to this bone is seen in the whale.

I gratefully express my indebtedness to Prof. Hughes for the loan of this specimen.

Discussion.

Prof. Leidy remarked that, although he had never seen the axis of a Dinosaur, the type of vertebra described was so like that of the succeeding cervicals of the genus *Hadrosaurus*, that he had no doubt the author was correct in his identification of it.

33. *On an* ORNITHOSAURIAN (DORATORHYNCHUS VALIDUS) *from the* PURBECK LIMESTONE *of* LANGTON *near* SWANAGE. By HARRY GOVIER SEELEY, Esq., F.L.S., F.G.S., Professor of Physical Geography in Bedford College, London. (Read May 26, 1875.)

IN the Christmas of 1868, when staying at Swanage, I was so fortunate as to obtain from a quarryman a portion of a large lower jaw, in association with a long vertebra, which indicate an Ornithosaurian animal of unusual size. Neck and jaw are parts to be expected in close association; but I see no reason to believe, or doubt, that the bones pertained to the same individual, though in the absence of conflicting evidence I shall be justified in attributing both specimens to the same species. As with all my findings, these were deposited in the Woodwardian Museum of the University of Cambridge, and briefly noticed in 1869 in my 'Index to the Aves, Ornithosauria, and Reptilia,' pp. 89, 90, the species being named *Pterodactylus macrurus.* I now offer some further description of the remains, and propose to place them in a new genus. The jaw cannot be located in the genus *Pterodactylus,* because no evidence exists of the occurrence in England of that genus (which, so far as I can discover, has been found only in the Solenhofen slate, and is represented by animals of small size), and because no specimen of *Pterodactylus* has the compressed, elongated, many-toothed, spear-shaped jaw on which I found the genus *Doratorhynchus.* *Pterodactylus* had the teeth in the jaw directed upward, and it is distinguished by having also a tail as short as that of a rabbit or deer; while this specimen (if the vertebra is caudal, and if the tail may be inferred from a single vertebra, five inches in length) would have had a tail unusually long and of considerable strength, and it possessed a flattened jaw, with teeth directed outward. The flattened jaw suggests *Cycnorhamphus suevicus* of the Lithographic slate as an ally; but since the vertebra, as I shall presently show, may be cervical, as may all those from the Cambridge Greensand which have been regarded as caudal, no definite generic character can be drawn from the vertebra alone.

The lower jaw.

The rami do not extend so far back as the articulation with the quadrate bone. So much of the specimen as is preserved measures 12¼ inches in length; and, where fractured behind, the rami measure 2¼ inches from side to side. The symphysis, beautifully preserved, extends for 5 inches. The jaw, at its anterior termination, where it expands a little, is nearly ¾ inch wide, while at the posterior termination of the symphysis it is an inch wide. The anchylosed portions of the rami are marked, as is usual, by a deep palatal groove. The teeth were very small and close-set, and have all fallen from their sockets.

This jaw is naturally compressed from above downward, so as to be scarcely more than an $\frac{1}{8}$ inch thick. The specimen gives no conclusive evidence that the jaw terminated anteriorly with the fragment of bone preserved, since the upper part of the bone of the anterior three inches of the symphysis is broken away and only the thin, inferior, investing, external layer of bone remains, and of that the anterior outline is not entire. This bone has its inner surface rough, a structure which probably indicates a roughened external vascular condition. The underside of the jaw is flattened, and very slightly convex from side to side. The anterior terminal inch is bent up slightly towards the upper jaw; and this probably shows that nearly the whole symphysis is preserved. The upper and lower surfaces of the symphysial portion of the jaw converge laterally to meet in the line of the teeth; the upper palatal surface has a flattened aspect, but is gently convex from side to side.

The sockets for the teeth appear to have been scarcely more than $\frac{1}{8}$ of an inch deep, and to have extended along at least 8 inches of the jaw. They are so arranged that in front of the jaw they may have been directed outward horizontally, while in passing backward they become steadily less and less inclined, till the hindmost sockets appear to have been vertical. A similar arrangement is found in some species of *Plesiosaurus*, and more or less in the buccal margin of the jaws of birds and many mammals. Each socket is ovate, with the anterior end a little raised; it is margined by an elevated rim, which is more prominent on the under, or outer, than on the upper or inner margin of the socket. In the middle of the jaw there appear to be 7 teeth in the space of an inch. The teeth appear to have extended for at least $3\frac{1}{2}$ inches behind the symphysis; but each ramus narrows rapidly from side to side to about $\frac{3}{8}$ inch in width, becomes deeper, and the palatal surface becomes rather more convex from side to side. The rami appear to widen again behind the teeth; but this is not quite clear, since for the hinder 5 or 6 inches only the lower surface of the fractured bone is preserved.

Sometimes the teeth are so closely packed together as to be parted only by a paper thickness, while sometimes interspaces occur as wide as a tooth. The palatal surface of the jaw is striated longitudinally. The palatal groove is so deep as to extend more than halfway through the jaw; it widens where it terminates behind to $\frac{3}{16}$ inch: and its basal surface is there elevated so as to divide the groove and prolong each half of it for some distance beyond the symphysis, down the inferior and inner side of each ramus.

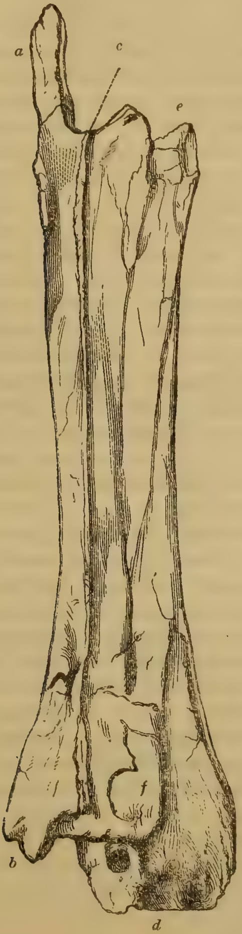
There is no evidence to show what elements of the lower jaw are preserved, or to indicate the length of bone lost between the hindmost fracture and the articulation with the quadrate bone. On the right inner side a small smooth surface of bone is shown; and this is probably the suture between the dentary and the angular bones.

The vertebra.

This specimen demonstrates the external layer of bone to have been more than usually thin, with extremely delicate cancellous tissue forming large meshes when the investing film of bone is removed. The fossil is somewhat obliquely crushed, the neural arch being pressed down on the centrum so as to extend beyond it on one side.

Along the length of the neural arch in the middle line, is a very narrow sharp ridge (*c*), slightly elevated at the anterior and posterior

Vertebra of Doratorhynchus validus, *Owen, from above.*
(Natural size.)



a. Anterior zygapophysis. *b.* Posterior end of the neural arch. *c.* Ridge in in the median line of the neural arch. *d.* Posterior articular end of the centrum. *e.* Anterior articular end of centrum. *f.* Cancellous tissue of bone from which the dense thin investing layer is broken away.

ends so as to be concave in length. The upper surface of the neural arch is limited anteriorly by a slight angle, which is prolonged backward; for the two sides slightly converge in passing backward from the outer margin of the præzygapophyses.

The præzygapophysis (*a*) is preserved on the left side only; the process is about $\frac{3}{4}$ inch long, it is narrow and carries a narrow zygapophysial facet, which looks inward and upward and very slightly forward. The anterior part of the neural arch between the zygapophyses is not developed so far forward as to quite cover the centrum. The transverse width across the zygapophyses was rather more than $\frac{5}{8}$ inch. In the median line the neural arch is $3\frac{3}{4}$ inches long; it is constricted, and in the middle the width is reduced to $\frac{5}{16}$ of an inch. The posterior end of the neural arch widens to fully $\frac{7}{8}$ of an inch, and is flatter and more expanded horizontally than the anterior end. It terminates $\frac{3}{8}$ inch from the end of the centrum. The posterior zygapophysial facets are not preserved. The lateral outline of the bone above and behind the zygapophysis terminates in a prominent tubercle.

The centrum appears to be about $\frac{3}{4}$ inch wide in front, and to be a little wider behind. In front the articular surface (*e*) seems to be concave from side to side, and was evidently shallow, as in the vertebræ from the Cambridge Upper Greensand. The posterior articulation (*d*) is not convex as in *Ornithocheirus*, but appears to be nearly flat, though the crushed condition renders its exact structure uncertain. As in vertebræ of *Ornithocheirus* from the Cambridge Upper Greensand, hitherto regarded as caudal, the pneumatic foramen is reduced to a small puncture, longitudinally ovate in form, less than $\frac{1}{3}$ inch long; it enters the bone from the front about the middle of the side, and looks more like the nutritive canal of the bone than a pneumatic foramen.

The largest reputed caudal vertebra hitherto found in the Cambridge Upper Greensand is $1\frac{1}{2}$ inch long, and relatively larger at the ends than this, which measures 5 inches in length.

When the cervical vertebræ of *Pterodactylus longirostris* are enlarged 6 diameters, they so closely resemble this type that I greatly doubt the propriety of continuing to regard this vertebra as caudal.

A detailed comparison with other genera and species may be reserved till other materials occur. I propose to change the specific name, because I have ceased to feel sure that the species had a tail; and until the species proves distinct, it may be incorporated with Prof. Owen's *Pterodactylus validus*, which is founded upon an isolated phalange of the wing-finger.

I offer my thanks to Prof. Hughes for his kindness in lending me these specimens and permitting them to be figured.

34. REMARKS *upon* MR. MALLET'S THEORY *of* VOLCANIC ENERGY.

By the Rev. O. FISHER, M.A., F.G.S. (Read May 12, 1875.)

THE theory of Mr. Mallet, F.R.S., contained in his now celebrated paper which was read before the Royal Society in 1872, has already been much discussed; but there seems to be still room for the following remarks, which I hope I shall not be thought presumptuous in laying before you.

The treatise is of such considerable dimensions that the simplest plan will be to take the sections of it in order as they occur, passing over those which approve themselves, and discussing only those which appear to be open to question.

There is nothing contained in the first eleven sections but what entirely commends itself to my judgment. Indeed some of the remarks of the distinguished author were anticipated in a paper of mine read at Cambridge in 1868, of which Mr. Mallet had no knowledge at the time when his theory was given to the world.

In § 12 the opinion that the crust of the earth rests on a liquid nucleus is mentioned, but not with favour. Whatever its condition may be at a very great depth, the view which at present seems probable to me is, that there is, at any rate, a substratum in a state of igneous fusion beneath the crust.

In § 15 Mr. Hopkins's investigation upon precession, according to which he believed himself to have shown that the crust of the earth is at present from 800 to 1000 miles thick, is referred to, but not with approval.

General Barnard, of the United-States Army, has satisfied himself that he has proved that Hopkins's investigation was vitiated by an oversight, and that no reliance can be placed upon his result*. There remain, however, the investigations of Sir. W. Thomson†, derived from considerations regarding the production of tides in the interior of the earth. These investigations are, I conclude, irrefragable as far as the mathematical part of the investigation is concerned. But there are some points in his argument on which something may nevertheless be said in favour of a liquid substratum beneath the crust of our globe.

The idea of a tide, which we derive from the flux and reflux of the sea upon our coasts, causes the popular conception of a tide to be different from the true one with which we have to deal in the case before us. What we have to imagine is, that the earth, which we may for the moment conceive to be a sphere, is drawn out into a prolate spheroid towards the attracting body, be it moon or sun.

Sir W. Thomson's argument, in the main, is this†. Unless the earth is immensely rigid, it will be sensibly drawn out in the manner

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* "Problems of Rotary Motion." Smithsonian Contributions, No. 240, New Addendum, p. 42.

† Phil. Trans. 1864.

‡ "On the Rigidity of the Earth," Phil. Trans. 1864.

described. If it be so, the fact will be betrayed in two ways; but the evidences which they will give of it will be totally distinct in kind.

One of these is, that the earth and the ocean being drawn up at the same place, the apparent ocean tide, or the increased distance between the bed of the ocean and its surface, will be smaller than if the solid earth was not so drawn up. Hence the observed ocean tide would be very considerably less than the calculated tide. Now he is of opinion that, if this were so, it might be observed. But he hesitates to speak very decidedly on this point, because great difficulties are introduced through the effect produced on the tides by the "irregular distribution of land and water, and of depth where there is water"*. Besides this, it seems to me that, in order to suit the argument in the form in which he puts it, it ought also to be shown that the crest of the tidal wave, if any exists in the solid earth, will occur at the same place as that of the ocean, which would, I conceive, not be the case, because the crest of the wave formed in the solid earth, consisting of such materials as he supposes, would occur immediately opposite to the attracting body†, while with respect to the ocean tide that would not happen‡.

The other manner in which the tidal deformation of the earth would be betrayed would be by the effect produced by it upon the phenomenon of precession. If it were fluid or elastic, and rendered oblate by its rotation, the same capacity for yielding which admits of the oblateness being produced, would also admit of the formation of tidal waves in the body of the earth by the attraction of the disturbing body. And their magnitude and position would be such as exactly to balance by their centrifugal action the precession-producing action of the disturbing body. In other words the disturbing body would produce two simultaneous effects upon the earth which would neutralize each other. In this case there would be no precession. If it yielded tidally to a certain extent, the precession would be reduced. Sir W. Thomson says§ that if it were no more rigid than glass, the precession would be reduced to two ninths of what it would be if it did not yield at all; and if it were no more rigid than steel, to three fifths. Observation, however, shows that precession is not thus reduced, and therefore proves that no such yielding as this can exist, and, consequently, that if the materials of the earth are of such a nature as to be liable to behave in the manner supposed under the attracting force, it must be rigid.

To the above argument the following objection occurs to my mind. The equatorial protuberance is such as the present rate of rotation would produce; and not only is there this protuberance at the sur-

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* Thomson, *loc. cit.*; also Natural Phil. §§ 843, 844.

† Phil. Trans., *loc. cit.* § 4. Compare with his paper "On Geological Time," Trans. Geol. Soc. of Glasgow, 1868, p. 6.

‡ Herschel, Phys. Geography, 2nd ed. § 66. If there were no friction it would occur 90° from the attracting body. See Trans. Geol. Soc. Glasgow, *loc. cit.* p. 6, note.

§ *Loc. cit.* § 26. See also General Barnard's "Problems of Rotary Motion," Smithsonian Contributions, No. 240, p. 37.

face, but all the interior surfaces of equal density follow a similar law, as is proved by the results of geodesy. Hence it follows that the earth must have been in a yielding condition at a time since which its velocity of rotation has been what it is now. But the phenomena of mountains show that there has been considerable contraction within geological periods*, which must have sensibly affected the rotation. The capability of yielding must therefore have continued up to a period comparatively recent; and if so, it seems most probable that it continues still; for the only change we can conceive would arise from refrigeration; and, with all the arguments we possess for a high interior temperature, it is very difficult to conceive that rigidity can be due to mere cooling.

Again, geological facts as regards climate appear to point to a change in the axis of rotation. But the equatorial protuberance corresponds to the present axis of rotation. A yielding condition, therefore, must have extended to Miocene times at least, and therefore probably to the present. That the globe should be bodily turned, or canted, over, as Mr. Belt supposes, is most improbable, if not impossible.

The idea of fiery lakes finds much disfavour with Mr. Mallet. I likewise mentioned some arguments against them in my paper on the elevation of mountains in 1868. Prof. Dana, whose authority is great, however, appears still to regard the idea with favour. But, for my own part, I must agree with Mr. Mallet.

For many sections forward from this point I am disposed to agree with Mr. Mallet's reasoning; and, indeed, to disagree with him upon questions that depend upon the laws of chemistry would be very presumptuous on my part. But, arriving at § 52, it seems that some important objections may be raised. We here meet with the author's views upon the formation of oceanic and continental areas.

Now I cannot at present offer any explanation of these grand features of the earth's surface. But, at the same time, any proposed explanation of them which is not the true one will, if not refuted, probably hinder a better one being sought. I shall be glad to hear, therefore, what geologists in general think of Mr. Mallet's opinion, which is also shared by Dana, that the oceanic and continental areas have, on the whole, occupied nearly the same positions on the globe at all periods from the very first. Certainly the marine origin of nearly all strata seems to point to an opposite conclusion; while the need of terrestrial conditions for furnishing the detritus to form the rocks which now constitute lands seems to me to require former continental conditions where the ocean now rolls. Notably around such an island as New Zealand there must have been much more land than at present to have furnished a series of formations extending from the Palæozoic to the Tertiary.

If it be not the case that these wide features of the globe have existed nearly in their present positions from the first formation of

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* See a paper by the author "On the Inequalities of the Earth's Surface viewed in connexion with the Secular Cooling," Camb. Phil. Trans. vol. xii. pt. 2, p. 18.

a crust, then the explanation fails that they were caused by unequal radial contraction when the crust was first permanently formed and thin. Neither do I understand how Mr. Mallet proposes to account for this unequal radial contraction. For, if the subjacent rocks up to that period still continued fluid, as it is supposed they did, the thin crust would have become corrugated in wrinkles of small dimensions, and not in wide depressions and elevations*. But if inequality of contraction be supposed to have produced the difference of elevation as between the ocean-bed and the continental surface, then, taking the coefficient of cubical contraction at 0·00002, which is what Mr. Mallet informs me is the mean, and supposing the crust to have cooled from 4000° F. to 0° F., we shall find that a thickness of thirty-eight miles will give us one mile contraction in the radial direction. Call the thickness forty miles: supposing, then, that from

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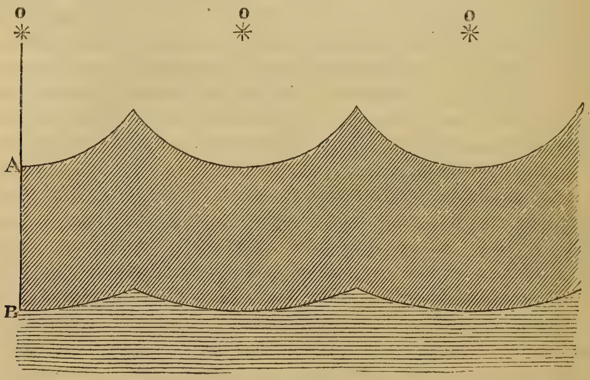
[*] I have proved, in a paper read before the Cambridge Philosophical Society in February last, that a flexible crust of small thickness, resting on a liquid, when compressed horizontally would assume a corrugated form, of which a section across the corrugations would exhibit a series of equal circular arcs, arranged in a festoon like manner as in the lower strong line of the annexed figure. The radii of these arcs would depend only upon the relative densities (ρ) of the crust and (σ) of the liquid and the thickness (c) of the crust, and would each be equal to $2\frac{\rho}{\sigma}c$.

Diagram showing the approximate Form of a Section of a Flexible Crust horizontally compressed and resting on a Liquid.

(The curves bounding the upper and lower surfaces are circles whose centres are O, O, O. The densities of the crust and liquid are supposed nearly equal; and therefore OB=2OA.)



In the case of the cooled crust of the earth, the crust can be only imperfectly flexible, and, the densities being nearly the same, the radii of the lower curves become each nearly $2c$. Consequently, if the curves have any appreciable length, the crust cannot be thin in the mathematical sense (that is in comparison to the other magnitudes in question). The above result can therefore be only taken as very approximately true. Nevertheless it seems a sufficient guide to what the general character of the corrugations would be to support the assertion made in the text.

some unexplained cause two contiguous areas have differed by as much as one tenth in the amount of linear contraction throughout (which is scarcely probable), it would require a thickness of crust of 400 miles to give occasion to one area being depressed one mile below the other. This is much more than can be considered a thin crust; and by the time the crust had attained that thickness, or, rather, the much greater thickness which would in reality correspond to the assumed amount of contraction, tangential pressures must have long ago come into play.

We now approach the main question, viz. that regarding the cause of volcanic heat. Mr. Mallet's "definition" is as follows:—

"§ 67. *The heat from which terrestrial volcanic energy is at present derived is produced locally within the solid shell of our globe by transformation of the mechanical work of compression or of crushing of portions of that shell, which compressions and crushings are themselves produced by the more rapid contraction by cooling of the hotter material of the nucleus beneath that shell, and the consequent more or less free descent of the shell by gravitation, the vertical work of which is resolved into tangential pressures and motion within the thickness of the shell.*"

The only questions here raised which I wish to discuss are those relating to the capability of the compression to give rise to volcanic action. As regards the lateral compression itself, I had found in 1868* the same value for its maximum amount which Mr. Mallet has arrived at. And, what is remarkable, in the MS. of my paper I used the very same proposition relating to the tension of a flexible vessel filled with fluid which he has used, in addition to the one which I have printed. I was, however, advised to retain a single proof as sufficient; and I retained the more elementary and independent one—which I somewhat regret, because the proof which I discarded (the same as Mr. Mallet's) answers an argument of Captain Hutton's, and shows that where the curvature of the earth is greatest, as at the poles, there the compressing force is proportionately increased; so that the compression theory is not encumbered with the difficulty that it ought to give all the mountain-ranges about the equatorial regions.

The subject of § 85, respecting the horizontal or tangential pressure *within* the earth, has regard to an inquiry which I made myself, and in which I arrived at the following result:—The lateral pressure within the earth, supposing any shell for a moment unsupported by the matter beneath, but partially supporting that above it, will be always greater than that at the surface (or than $\frac{1}{2}g\rho R$), until some point is reached which cannot be further from the centre than two fifths of the radius, and is probably much nearer to it. There the internal horizontal pressure will be equal to that at the surface. After that it becomes smaller, and eventually, near the centre, vanishes.

No question can therefore be made that it will be sufficient, at all such depths as we are concerned with, for any call that may be made upon it for crushing the strata of the crust of the earth.

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* Trans. Camb. Phil. Soc. vol. xi. pt. 3, p. 489.

But the great question is, will such crushing, if it occurs, produce volcanic phenomena?

On entering upon this part of Mr. Mallet's paper I cannot but express my admiration for the amount of laborious, and apparently accurate, experimental investigations which he has gone through. The records of these alone render his memoir of lasting value.

The bearing of his experiments of crushing rocks upon estimating the quantity of heat obtainable by that means appears thus:—The tangential pressure within the earth's crust is practically unlimited. If, therefore, any obstacle was interposed to keep it apart along a certain vertical section, and held there until the pressure had attained its full value, and the obstacle then suddenly removed, the pressure being enormous, the energy with which the two faces of the section would rush together would be enormous; and the work convertible into heat, being the product of the pressure into the distance between the faces of the chasm, would be sufficient to educe a proportionately large quantity of heat. But in the case of nature the supposed obstacle is no other than the rock itself, and the amount to which the pressure can accumulate is just that which the rock will bear without becoming disintegrated; and were this event to take place, as Mr. Mallet supposes, the space through which the pressure acted would be that which could be gained out of the closer compacting of its particles.

No doubt the conditions would be largely affected by the state the rock might be in at great depths, and by the compression to which it would be subject from the weight of the overlying strata. But these rather tend to lessen the space through which the pressure could cause motion, and so to lessen one factor in the expression for the amount of heat obtainable. From the different circumstances of the cubes experimented upon by Mr. Mallet, free on three sides, and consequently allowing a greater descent of the plunger, I think it may be assumed that the quantity of heat he calculates upon is probably a fair estimate even under the circumstances of the increased pressure found in the case of nature.

If I have rightly understood the description of the experiments, they may be shortly thus explained:—Cubes of rock, of $1\frac{1}{2}$ inch on the edge, were crushed under a cylindrical piston or plunger of $3\frac{1}{2}$ inches diameter.

The pressure upon each square inch of the face of the cube was calculated from the known pressure laid upon the plunger; and the vertical descent of the plunger while the crushing was going on was also obtained. These, multiplied together, gave the work of crushing; whence, with the help of known constants, the heat evolved was calculated, it being supposed that all the work was converted into heat.

Let us now consider the summary of the series of experiments in crushing the cubes of rock as given in Column 19 of Table I. The numbers there represent the vertical range through which the pressure acted in crushing the cubes of rock. Turning to fig. 9 and § 116, it seems to me that the length of these ranges must have been largely influenced by the cube experimented upon having been free on four of its sides. If it had been confined in a box of its exact size it might still have been crushed; but the amount of descent would have been in that case dependent solely upon the increase of density which could be given to it after disintegration by the pressure. If the box had been somewhat larger, the plunger would have descended further, and if the rock was altogether unsupported, as seems to have been the case, further still. Now I do not question that the value of H (the heat) found in accordance with the experiment is correct; but I do question, as already stated, the form of the experiment representing at all closely what would happen deep in the earth's crust. It seems to me the cubes should have been confined, and that the experiment in § 99 more closely represents the case of nature.

But I will accept the results as given in columns 26 and 28, which give the final effects of crushing upon the temperature of the rock. The mean number of British units of heat developed by crushing one cubic foot of the harder rocks is there put down at 5650; and the mean temperature by which a cubic foot of such rock would be raised I make to be 172° F. Or if we take the particular kinds of rock selected by Mr. Mallet (§ 133), these means are found by him to be 6472 and 184° F. And if the rock was previously at 300° F., taking 2000° as the fusing temperature, he makes 0·108, or rather above one tenth, as the fraction of a cubic foot of rock which the heat developed by crushing *one* cubic foot of rock could fuse. Or, to put it otherwise, it would require the heat developed by crushing *ten* volumes of rock to fuse about *one*.

Here is the point at which I cease to follow the distinguished author. He considers that the heat so developed may be localized, and that the heat developed by crushing, say ten cubic miles of rock, may fuse *one* mile. But, I ask, how so? The work is equally distributed throughout. Why should not the heat be so also? Or if not, what determines the localization? For example: suppose a horizontal column ten miles in length and one in sectional area to be crushed by pressures applied at its ends. Which of the ten cubic miles is to be the one fused? But if no cause can assign one rather than another, it is clear that they will all be heated equally by 170° F., and none of them fused.

To take an analogous case by way of illustration:—Suppose a railway train in motion with n wheels to be stopped by a single brake in a given time. Heat enough may be developed to produce sufficient rise of temperature in the brake to burn it. But if a brake be applied to every wheel with an equal pressure on each so as to stop the train *in the same time* as before, each brake will be heated by $\frac{1}{n}$th of the amount by which the one brake was heated in the first case; and none of them need be burnt. And if some of them are not burnt, certainly the rest will not be so. If I may be allowed to use the word, the fallacy appears to lie in the *application* of the principle expressed in § 66, where we read:—"The work thus developed is transformed into heat; that heat is greatest along those lines, or planes, or places, where movement and pressure together constituting work are greatest." This is, no doubt, true. Suppose a column of rock 100 miles long compressed, and that a length of 90 miles of the rock is so much stronger than the remaining ten as to resist crushing. Then all the heat produced would be developed in those ten; but not more could be developed than enough to raise each of them by 170°, and that would be the case with all the ten, so that no fusion could arise. Indeed the form in which the objection to Mr. Mallet's reasoning suggested itself to my mind on first reading his paper was simply this. *If crushing the rocks can induce fusion, then the cubes experimented upon ought to have been fused in the crushing.* And I still adhere to that simple mode of expressing my objection.

In arguing thus I have assumed, what appears to be assumed by Mr. Mallet, that as soon as the rock is crushed the work is completed; so that, as no more motion can be obtained, so no more heat can be developed. The result of compressing a gas would be different.

From § 135 to § 172 we have the description of a valuable series of experiments upon the fusion and contraction on cooling of slags and other substances*. It appears that the slags on leaving the furnace were at about 4000° F., and at the period of incipient solidification at 3000° F., from which it seems that 2000° F., which is the temperature assumed in § 133 for melting rock, is lower than the experiments justify.

From § 174 to § 181 comparisons are made between the heat lost by the earth and the quantity of rock which would need to be crushed to supply it.

In § 175 it is calculated that the diameter of the earth has shrunk by 189 miles, at least, in passing from a state of fusion at 4000° F. to its present state. In this estimate I cannot concur, because it assumes, as appears by making the calculation, for the ratio of the original to the contracted volume, 1000 : 933, as given in § 161. In other words, it assumes the entire globe to have cooled to the temperature of 53° F., which is clearly inadmissible.

From § 183 to § 201 we meet with a calculation to prove that "the crushing of the earth's solid crust affords a supply of energy *sufficient* to account for terrestrial vulcanicity," and "that the necessary amount of crushing falls within the limits that may be admitted as due to terrestrial contraction by secular refrigeration."

But if I have succeeded in showing that crushing of the rocks cannot *fuse* them, these propositions are beside the mark.

There are, however, certain strictures which it appears nevertheless desirable to make upon this part of the paper. In the first place no allowance is made for energy expended in elevating any part of the crust by corrugating it. The elevation taken account of is only that of the formation of volcanic cones, and even in that elevation the

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* I have largely availed myself of Mr. Mallet's results in my late paper "On the Inequalities of the Earth's Surface &c.," already referred to, and take this opportunity of expressing my obligation to him, not only for his important published results, but for private information and valuable help.

work expended is reckoned only for raising the centre of gravity of the cone above its base; whereas, in fact, the energy ought to have been calculated upon the height to which all the dust and lapilli would have been shot up into the air, on the supposition that it had taken place *in vacuo*. To take a parallel case:—If a ball were fired vertically from a cannon, no true estimate of the energy expended would be obtained by multiplying the mass of the ball by its radius —the height of its centre of gravity after it had fallen to the ground.

Such are some of the objections which have occurred to me upon a somewhat mature consideration of Mr. Mallet's now celebrated theory.

DISCUSSION.

Prof. SEELEY regretted that Mr. Fisher had not seen his way to a wider discussion of some of the interesting subjects of his paper; thus the figure of the earth might be better understood if it were also considered how far such a form might result from expansion of the earth arising from the equatorial heat of sunshine. He said, on the hypothesis that the earth was homogeneous and formed of copper, it would expand about 1 part in 35,000 for every degree of increase in temperature; and starting with the hypothesis that an equatorial temperature of 30° F. had in this way been raised 50° to 80° F., and that this temperature extended to the earth's centre, then an expansion of 50 parts in 35,000 would go far towards accounting for a difference between the polar and equatorial diameters of a world.

Another point was the origin of continents. He did not think that the explanations at present given exhausted the subject; and remembering that the lifting power of the moon corresponded to about one 250,000th part of the earth's weight, and that the sun supplemented this with a power half as great, he ventured to suggest, since the earth's surface is thrown into folds which are proved, by fringing reefs and atolls, to be alternately rising and falling, that these movements might be explained, in part at least, as the effect of tidal movement in the earth itself.

Mr. PEACOCK thought that neither Mr. Fisher nor Mr. Mallet had given sufficient consideration to the force of steam.

Prof. RAMSAY said he rose not so much to criticise Mr. Fisher's paper as to ask for information. He thought it might be possible to arrive by calculation at the time when the earth's crust became exceedingly thick, but we could know nothing about a first thin crust from the study of existing rocks now at the surface. In that sense the Laurentian rocks are not of extreme antiquity; for the sediments of which they were formed were derived from preexisting continents, composed as at present of stratified and igneous rocks. In fact we know nothing positive of a time when the crust of the earth was so thin as to be capable of bulging out under the influence of external attraction. Prof. Ramsay referred to Mr. Hopkins's notion of the fluid interior of the earth being affected by tides produced by the attraction of the sun and moon, and remarked that now there could be no precisely definite line of demarcation between the fluid interior and the solid crust, and that the crust probably was so thick and rigid as to press on the fluid interior, and effectually prevent any such tidal action as was described. He admitted that great oscillations have taken place, but thought that all continental areas existed as such in very early geological times, and he illustrated this opinion by discussing the geological history of Europe. With regard to the notion that pressure due to shrinkage might produce fusion of rocks, he remarked that he had suggested the possibility of such being the case in his Presidential Address to the Geological Section of the British Association at its Meeting in Nottingham in 1866.

Mr. BLAKE remarked that as all agreed that the earth was a cooling, and therefore a contracting body, the pressures and strains arising from unequal contraction must do work of some kind. It is impossible that there should be any sudden descent of an exterior shell on account of the shrinking of an inner one, as it would involve a vacuum within the earth ; but the more probable account would appear to be this :—There are continual strains going on within the earth ; and these, when long continued in a gradual manner, may give rise to contortions in rocks, as shown by the experiments of Mr. Miall, the heat produced being gradually dissipated ; but when a mass of rock breaks down under accumulated pressure, the heat developed suddenly may be too great to be dissipated, and the rock may be melted by the heat, the suddenness of the breaking down being an essential element in the process.

Mr. FISHER, in reply, said that he had read Leconte's papers, and did not think there was much in that writer's views beyond what had been referred to in the paper. He thought that the influence of attraction was not sufficiently understood, and that there was no doubt the attraction of such a body as the moon might be capable of producing change in the form of the earth. He could not agree with Prof. Ramsay in thinking that the present continents had always been continental ; but the fundamental Laurentian rocks being themselves aqueous deposits was an answer to that assertion. Mr. Mallet's period of a thin crust must have been antecedent to these.

35. NOTES *on some* PECULIARITIES *in the* MICROSCOPIC STRUCTURE *of* FELSPARS.

By FRANK RUTLEY, Esq., F.G.S. (Read May 26, 1875.)

[PLATES XXIII. & XXIV.]

As the different striations presented by various sections of felspars when viewed by polarized light under the microscope are, I believe, regarded by many observers as very strong if not absolutely conclusive evidence of the crystalline system to which those felspars belong, and since determinations upon this point are matters of the utmost importance to the petrologist, I have endeavoured to ascertain, so far as I am able, the real value of some of these phenomena as tests in microscopic inquiry. In 1869 Kreischer observed a series of striæ in sections of yellowish brown pegmatolite and in a flesh-coloured felspar from Arendal, which crossed one another at right angles—the one system lying horizontally at right angles to the principal axis, whilst the other followed the direction of the basal plane; and he noticed these striations in sections taken parallel both to the basal and to the clinodigonal cleavages*.

Stelzner suggested that this appearance was due to the mineral being composed not merely of coarse lamellæ, but of an intergrowth of two systems of finer ones, one system lying parallel to the orthopinakoid, the other parallel to the clinopinakoid, which traversing one another in opposite directions were subdivided into rod-like forms†. These striations have subsequently from time to time attracted the notice of different observers; and whenever they occur in a felspar it is regarded as orthoclase. I doubt whether any perfectly satisfactory explanation of this phenomenon has yet been offered; and it seems to me better to study the effects before attempting to deal with the cause. A careful examination of microscopic appearances will probably do much towards teaching us the real character of these markings, and may at the same time help, to some small extent, to demonstrate those points of structure which constitute the groundwork of crystal architecture. The following notes refer to various peculiarities of structure which I have observed in different felspars; and it is my object to show how much credence can be placed in certain microscopic appearances, in the discrimination of orthoclastic and plagioclastic felspars.

Fig. 1, Plate XXIII. represents part of a section of orthoclase from Arendal, seen by polarized light under a magnifying power of 50. In this the cross-hatched striation is well shown; but the most peculiar feature consists in the occurrence, in this portion of the section, of some coarser lamellar particles or crystals which follow two definite directions, these directions intersecting at an oblique angle, the alternate angles measuring about 75° and 105°. The directions assumed by these plates or crystals appear to lie in positions inter-

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* Neues Jahrb. f. Mineral. 1869. p. 208.

† Berg- u. hüttenmänn. Zeit. xxix. 150.

mediate between the directions of the rectangular striations. Now it is evident that lamellæ and other inequiaxal bodies do not assume definite directions either in rocks or in minerals without some good cause; and in the present case I think these coarser lamellæ or crystals may be taken to evince the presence in this mineral of structural planes other than those indicated by the cross-hatched striation. As this section corresponds in general respects with other sections of orthoclase which I have cut parallel to the basal cleavage, and as, besides the observers already cited, Rosenbusch and others state that these striæ run, the one set parallel, and the other at right angles to the edge formed by the faces OP and ∞P′∞, it seems that these coarser plates or crystals lie in directions parallel to the ∞P planes; for although the angles 105° and 75° do not agree with the angles formed by the ∞P planes in orthoclase, yet the discrepancy may be accounted for by the oblique direction in which, if really parallel to ∞P, they are here viewed, assuming that the plane of section coincides with the basal plane, in which case the divergence of the plane of section from a plane at right angles to ∞P would be 22° 16′, since the observed inclination of oP on ∞P is 67° 44′. Such an obliquity in the direction of the plates to the direction of vision would suffice to augment one pair of alternate angles some 10 or 15 degrees, and to proportionally diminish the other pair. And, as Rosenbusch records an instance of lamellæ of albite assuming a similar direction, it seems highly probable that further research will give us more evidence of some structure in orthoclase parallel to the ∞P faces. Several observers have expressed the belief that the cross-hatched structure is connected with the rectangular cleavages of orthoclase; but from an examination of the broken edges of several sections in which this structure is shown, I have found remarkably perfect cleavage in one direction, but most unsatisfactory indications of it in the other—a discrepancy far greater than one would have anticipated from the well-defined cleavages which occur in both directions in hand-specimens. The accidental fractures on the edges of very thin sections, however, are scarcely to be regarded as of much importance, except in cases where cleavage is very perfect and easily produced. One of the points which I especially wished to ascertain was whether the cross-hatched striation, just alluded to, was ever partially developed; for this purpose it appeared best to examine small imbedded crystals. Fig. 2 Plate XXIII. represents a crystal occurring in perlite from Schemnitz. As is rather common in crystals imbedded in perlites and pitchstones, the angles are somewhat rounded. Upon one side, extending over a limited area, and upon one side only, is the cross-hatched striation visible in this crystal. Lines of accretion are shown in other parts; but the cross-hatching is only partial. It may be objected that we do not know the direction in which this crystal is cut—that if cut in some other direction it would show the cross-hatching throughout. I very much doubt it. To obviate the difficulty of such an objection, the section, part of which is shown in fig. 5, Plate XXIII., may be referred to. This section (magnified 115 diameters) is cut from a milk-white felspar from Twedestrand, in Norway. The principal cleavage of the specimen is marked by beautifully regular and parallel striations, visible to the naked eye; and to all appearance the felspar is a triclinic one, in outward aspect resembling oligoclase. In thin section under the microscope, when seen by polarized light, it displays in different positions of the Nicols even sheets of colour alternately pale blue and pale orange, and shows, in places, broad bands, feeble in tint but with well-defined margins. Scattered throughout the mass are little irregularly shaped patches which show the cross-hatched striation most distinctly. These patches are, no doubt, orthoclase*. Their striation invariably corresponds in one of its directions with the broader striation of the surrounding mass. Having ascertained this point, it remained to be shown whether any of these patches exhibited partial striation; for here no valid objection could be raised on the score of the sectional planes not being the same, as, although the markings in some of the isolated patches became more faint in one direction, similar markings in other patches became fainter in a direction exactly opposite, as shown in the accompanying drawing. If, therefore, widely distant patches in the section exhibited the cross-hatching over their entire surfaces, it was obvious that if the cross-hatching were partially absent in any patch the defect could not be due to any deviation of the plane of section. Several patches occur in this section in which the cross-hatching is only partially displayed. One such patch is shown in fig. 6, Plate XXIII., under a magnifying power of 350 diameters. A section of oligoclase from the zircon syenite of Hamilton Sound, Labrador, collected by my friend Mr. Bauerman, exhibits included patches of cross-hatched orthoclase similar to those just described. It appears needless to multiply instances of partial failure in the development of this structure. It is sufficient for me to demonstrate the facts; theories concerning their cause I leave to other and more skilled observers. The next thing to do was to find cross-hatched and unstriated or simply striated matter symmetrically distributed in one and the same individual. In fig. 3, Plate XXIII., we meet with such an example in a twinned sanidine crystal in trachyte, from Berkum, on the Rhine. This section is magnified 115 diameters (the same power as that employed in the delineation of fig. 5). We here notice that the striations transverse to the longer diameter of the crystal are much more delicate than in fig. 5, that they are crossed at right angles by bands some of which are apparently coarser, and that they occupy well-defined areas which are segments either of circles or ellipses on either side of the crystal, while the terminal spaces are unstriated or marked only by very feeble striæ, which assume directions approximating to those of the two arcs which form the large internal boundaries.

We now come to a remarkable form, which may serve in some measure to elucidate points of structure in the foregoing example.

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* Allusion was here made to the observations on the intergrowths or admixture of different felspars recorded by Tschermak in his well-known paper, Sitzungsberichte d. kais. Akad. Wiss. Wien, Bd. i. Abth. i. 571 (1864).

Fig. 4, Plate XXIII. is the drawing of a crystal selected from many others of a similar nature. These crystals occur, mostly in radiate or fan-shaped aggregates, in a dark spherulitic-looking obsidian from Mexico. The specimen was given me by Mr. H. W. Bristow. In outward aspect it resembles a very bad sample of bottle-glass, but under the microscope is one of the most beautiful and intensely interesting specimens that I have ever seen. With the exception of the crystal aggregates just alluded to, the glass is wonderfully free from any impurities, containing only clear spherical bubbles, which by refraction show numerous sharply defined concentric rings. The crystals present the appearance of being either partially developed or partially disintegrated, either as though the process of crystallization had been rapid and suddenly arrested, or as though the crystal had been partially dissolved and the process suddenly stopped, leaving a beautifully dissected structure, the very framework apparently of the crystal. In the instance here figured, and which is represented as seen by dark-ground illumination, the framework consists of two well-defined arcs or, rather, hyperbolic curves resembling those in the example just described, which span the crystal longitudinally, their concave aspects girding the exterior lateral portions of the crystal. These arcs are quite distinct and separate; they are thickest in the middle, tapering gradually towards their ends, which reach the extreme corners of the crystal. From each of the four cornua processes, which, I believe, are pectinate in character, are given off on either side of the main rib in directions which apparently correspond with the direction of the corresponding portion of the adjacent main rib; hence they do not form right angles with the limb from which they are developed. They have a delicate feathery appearance, and disappear towards the thicker, median portion of each arc in this particular crystal. The dark patch in the corner of the drawing represents the glassy magma; the light portion indicates part of a large underlying crystal which is out of focus. We see in the framework of this crystal the same large divisional lines which mark off the striated and, at times, unstriated areas in the sanidine crystal from the Berkum trachyte. We see also in this instance either that development of striæ commences at the angles, or that disintegration begins midway along the sides. Fig. 1, Plate XXIV. shows a very minute, I might say embryonic, crystal occurring in this Mexican obsidian, magnified 240 diameters; unfortunately it is mounted under a glass cover which is too thick to permit the use of a higher power. We here see a straight stem which gives off straight processes on either side. These processes run at an oblique angle to the main stem, the one set forming with the other set an angle of 115°, as nearly as I could measure it under so low a magnifying power. Other processes are given off from them, which we will, for convenience, call secondary processes; these may pass from either side of the primary processes, and appear to follow two directions, one of which is parallel to the main stem, while the other is parallel to the opposite series of primary processes; so that these secondary processes also make an angle of 115° with one another, as roughly represented in fig. 2, Pl. XXIV., their stems (the primary processes) deviating from the original main stem by about fifty-seven and a half degrees. These must, however, be regarded only as roughly approximate measurements.

In fig. 5, Plate XXIV., another crystal from the same section is represented. In this instance there is a midrib which bisects the crystal longitudinally for some distance. It then bifurcates, the forks passing to the angles of the crystal. The angle between this fork is approximately 42°; I do not think it follows that because of this great discrepancy in the angles formed by the structural lines in these crystals they are therefore different minerals.

On measuring roughly the angles formed by a drop of chloride-of-ammonium solution evaporated on a glass slip, I noticed very great variation in the angles formed, some of them ranging between 72° and 90°. Fine striæ follow the directions of these forked boundaries in every part of the crystal, intersecting one another at the same angle, viz. 42°. The striæ in these crystals from the obsidian differ from those so characteristic of the Norwegian, Swedish, and other massive examples of orthoclase, inasmuch as they are distinctly visible by ordinary illumination, and under crossed Nicols merely appear white, while only the faintest indications of the other striæ are occasionally visible under such circumstances, and polarize, at times, in the most brilliant colours. There seems therefore but little analogy between them. Still it is noteworthy that the great divisional markings in these crystals bear in some instances a strong resemblance to the great divisional markings in the felspar crystals of the Berkum trachyte already alluded to; and although I cannot say precisely to what mineral species the crystals in the Mexican obsidian may be referred, still it seems quite possible that they are felspars of some kind; and their striking resemblance to the little felspar crystals in the Berkum trachyte, in the arrangement of the larger divisional markings, sufficiently warrants me, I think, in endeavouring to draw some comparison between them. In fig. 6, Plate XXIV., portions of some plagioclase crystals from the gabbro of Volpersdorf, near Neurode, in Silesia, are represented. The right-hand crystal shows several well-marked transverse bands, which cross the longitudinal ones at right angles. The left-hand crystal exhibits only the usual longitudinal bands. I have no doubt that both of these crystals are plagioclase; and it is therefore interesting to find an example of a triclinic felspar in which cross-banded structure is developed, no matter on how trivial a scale. Figures 4 and 9, Pl. XXIV. show similar appearances in crystals imbedded in basalt from Cleveland. I have now directed attention, so far as I am able, to instances in which we find orthoclase displaying complete cross-hatching, partial cross-hatching and failure of striation, partial cross-hatching and simple longitudinal banding and, as in fig. 3, Pl. XXIV., apparently partial transverse striation coupled with an absence of striæ. I have also pointed out the existence of peculiar divisional markings which sometimes divide cross-hatched from simply striated areas, and which in other instances may divide areas all of which show crossed striæ, although those striations do not run at right angles. Attention has also been directed to the occurrence of transverse bands crossing the longitudinal bands in plagioclase; and I now leave it for others to decide how far such phenomena strengthen or weaken the value of those tests by striation on which microscopic petrologists have, at present, to rely so much. I am inclined to think that examples such as those now brought forward occur rather exceptionally, and that our belief in the existing method of microscopically distinguishing orthoclase from the triclinic felspars need in no way be shaken, as a rule. Still it is well to bear in mind the fact that exceptional cases may occur more frequently than we anticipate, and it seems quite possible that by careful examination of these cases we may acquire a few additional scraps of knowledge respecting the structure of crystals and the value of the microscopical tests which we are in the habit of using.

On Plate XXIV. a few other examples are given, illustrative of the points already discussed in this paper.

From what has already been observed and recorded by the best microscopic petrologists of the day it seems to be an established fact that orthoclase in thin section under the microscope polarizes either in uniform sheets of colour or in sheets of varying colour, the variation being due to differences of thickness in different parts of the section—that crystals of orthoclase, when twinned on the Carlsbad type, polarize in complementary colours on opposite sides of the twinning plane, owing to a difference in the direction of the elasticities in the component halves of the twin—that some massive, cleavable kinds of orthoclase, such as those from certain localities in Norway, Sweden, and elsewhere, exhibit a cross-hatched rectangular banding, often in strong colours, when seen by polarized light—that the triclinic felspars may under similar circumstances, when cut parallel to the twinning-planes, exhibit only monochromatic polarization, under which conditions they may be confounded with sections of orthoclase—that it is a doubtful, although not an impossible thing, that a crystal of triclinic felspar may be only once twinned and thus again simulate orthoclase—that crystals of triclinic felspars are almost invariably many times twinned, thus giving rise to parallel banding of different tints when cut transversely or obliquely to the twinning planes, the bands having in the former case sharply defined margins, while in the latter instance they may soften into one another on revolution of one of the Nicols—that some of these bands in triclinic felspars occasionally end abruptly, and that in altered conditions either of orthoclase or plagioclase a more or less granular structure supervenes, which often renders it difficult or impossible to distinguish between them. So far as my limited experience goes, I can indorse these statements, but I am not aware that any exceptional instances such as those which I have pointed out, have yet been recorded.

There remains one more point to be mentioned with regard to the banding in plagioclase crystals under polarized light; and to this I do not think petrologists have hitherto given much consideration. If a section be cut obliquely to the twinning-planes, and if the alternate planes polarize in complementary colours, there may be (as indicated in fig. 10, Pl. XXIV.) an overlap of the different lamellæ, which would result in the recompounding of the coloured light, and thus give rise to bands of ordinary white light, which under crossed Nicols would appear dark; and these bands would occupy the areas lying between the upper and lower sections of the obliquely situated twinning-planes (*w*, *w*, *w*, fig 10). Supposing the section to be cut still more obliquely to these planes, as in fig. 11, Pl. XXIV., the overlaps would occur in a continuous series, so that although the entire section might consist of numerous twin lamellæ, there would be no coloured polarization to evince their presence. Fig. 8, Pl. XXIV. shows two dark bands (under crossed Nicols) bordering a twin lamella, in a plagioclase crystal from a section of basalt from the Cleveland District, given me by my friend Dr. Fritzgärtner. Fig. 7, Pl. XXIV. is a very curious little crystal occurring in the same section of Cleveland basalt. The elliptical area surrounds a small dark speck; and although the crystal is twinned, the boundary line of this internal area does not appear to have been affected, and it may, I think, have been produced subsequently to the development of the twin. A small band is visible in one of the halves of this twin, also running parallel to the longer axis of the crystal. This appears to be one of those difficult examples in which the observer cannot help feeling doubt as to the system to which to refer the felspar. The feeble stripe just alluded to, and its occurrence in a basalt, are the only evidence to support its claim to be regarded as plagioclase. The occurrence of orthoclase in basalts has already been pointed out by Mr. Allport, in his paper on the Carboniferous Dolerites read before this Society last year; and although most observers regard it as a doubtful question, and Zirkel considers such crystals, if they do so occur, to be merely sporadic, still I am inclined to think that Mr. Allport's conclusions on this subject are not far from the truth, and that orthoclastic crystals are of more frequent occurrence in some dolerites than has hitherto been suspected. I do not, however, believe that they could occur to any great extent: if they did, the character of the rock would be completely changed; it would no longer be dolerite.

In all these matters, I believe that the micro-petrologist does well to be guided by prevailing opinions; but if progress is to be made, the truth of those opinions should be tested rigidly; and the demonstration of small facts may then enable him to grapple with larger questions. Although we may be able to deal speculatively with large questions affecting rock masses and their origin, still, in the absence of demonstration, doubt will always exist, and we can never be the masters of those questions until we understand the details of which they are built up.

Supposing the foregoing statements of the means at present at our disposal for the microscopic determination of monoclinic and triclinic felspars to be correctly given and to represent the truth, the conclusions at which I arrive from the observations now described may be briefly summed up as follows:—

i. That massive varieties of orthoclase often exhibit a cross-hatched striation, as already noticed by many observers, but that these striations do not represent all the structural planes directly or indirectly demonstrable which internally traverse the cleavable mass.

ii. That this structure is not yet satisfactorily accounted for, being sometimes accompanied by strongly chromatic effects, suggestive of twinning, under polarized light, while at other times under similar circumstances the same structure appears to be represented merely by divisional lines which do not offer any differences of colour such as one would expect from a twinned structure of the mineral.

iii. That this structure is often visible in patches imbedded in felspars which merely show parallel banding.

iv. That both in such patches and in some definitely developed crystals the cross-hatched structure may extend over only a very limited area, and that the remaining portion of the patch or crystal may only exhibit parallel banding or no banding at all.

v. That, in composite instances such as these, we are as yet unable to determine by microscopic means the system to which such a crystal or patch should be referred.

vi. That there is a structure developed in the sanidine crystals of some trachytes analogous to a structure to be found in the crystals occurring in the Mexican obsidian just described, some of these crystals appearing to be also identical with some crystalloids formed in a furnace-slag which was examined and described by the late Hermann Vogelsang.

vii. That the sanidine crystals just alluded to are twinned and may be regarded as true crystals, and that, if so, there is but little distinction to be made between some crystals and crystalloids.

viii. That the crystals or crystalloids in the Mexican obsidian show great discrepancy in the angular intersections of their internal striæ or divisional planes, but that this does not invalidate the assumption that they belong to the same species, since a drop of solution of chloride of ammonium evaporated on a glass slip will show a variation of angles from about 72° to 90°.

ix. That the present method of discriminating between monoclinic and triclinic felspars answers sufficiently well for ordinary purposes, but that it is often inadequate for the determination of doubtful examples, and that such examples are of more frequent occurrence than one would at first be led to suspect.

x. That the estimate of the number of twin lamellæ occurring in crystals of plagioclase, as given by some observers, is liable to error, the obliquity of some sections tending to augment the apparent number of the lamellæ by the overlap of adjacent plates which polarize in complementary colours.

EXPLANATION OF PLATES.

PLATE XXIII.

Fig. 1. Orthoclase, Arendal, showing crystals arranged in two directions, other than those of striation. × 50 (polarized light).

2. Felspar crystal in perlite, Schemnitz, Hungary, showing partial cross-hatching. × 55 (polar.).

3. Crystal in trachyte, Berkum, near Bonn, Rhine, showing internal curved divisional markings, with lines crossing at right angles in the lateral areas. × 115 (polar.).

4. Partially formed, or partially disintegrated crystal in obsidian, Mexico. × 175 (dark-ground illumination).

5. Patches of cross-hatched felspar in oligoclase, Twedestrand, Norway. × 115 (polar.).

6. One of the above patches, showing partial cross-hatching. × 350 (polar.).

PLATE XXIV.

Fig. 1. Minute crystal in obsidian, Mexico. × 240.

2. Diagrammatic exaggeration of the above.

3. Crystal from trachyte, Berkum, Rhine. × 90 (polar.).

4. Crystal from basalt, Cleveland, showing rectangular banding and subordinate oblique striation, the latter possibly indicating planes connected with twinning on the Baveno type. × 45 (polar.).

5. Crystal in obsidian, Mexico. × over 100.

6. Crystals of plagioclase in gabbro, Volpersdorf, Silesia, showing bands at right angles. × 90 (polar.).

7. Crystal in basalt, Cleveland, Yorkshire. × 45 (polar.).

8. Fragment of plagioclase in basalt, Cleveland, showing alternately dark and light bands fringing an obliquely cut twin lamella, as in fig. 10. × 45 (polar.).

9. Crystals on edge of section of basalt, Cleveland, showing cross-hatched striation and a rectangular cleavage at *x* on the outer edge of the section. × 45 (polar.).

10. Diagrammatic vertical section through a section of plagioclase cut obliquely to the twinning-planes: the spaces marked *w* would alternately appear light and dark in different positions of the Nicols when seen by polarized light, the overlap of the complementary colours giving rise to white light.

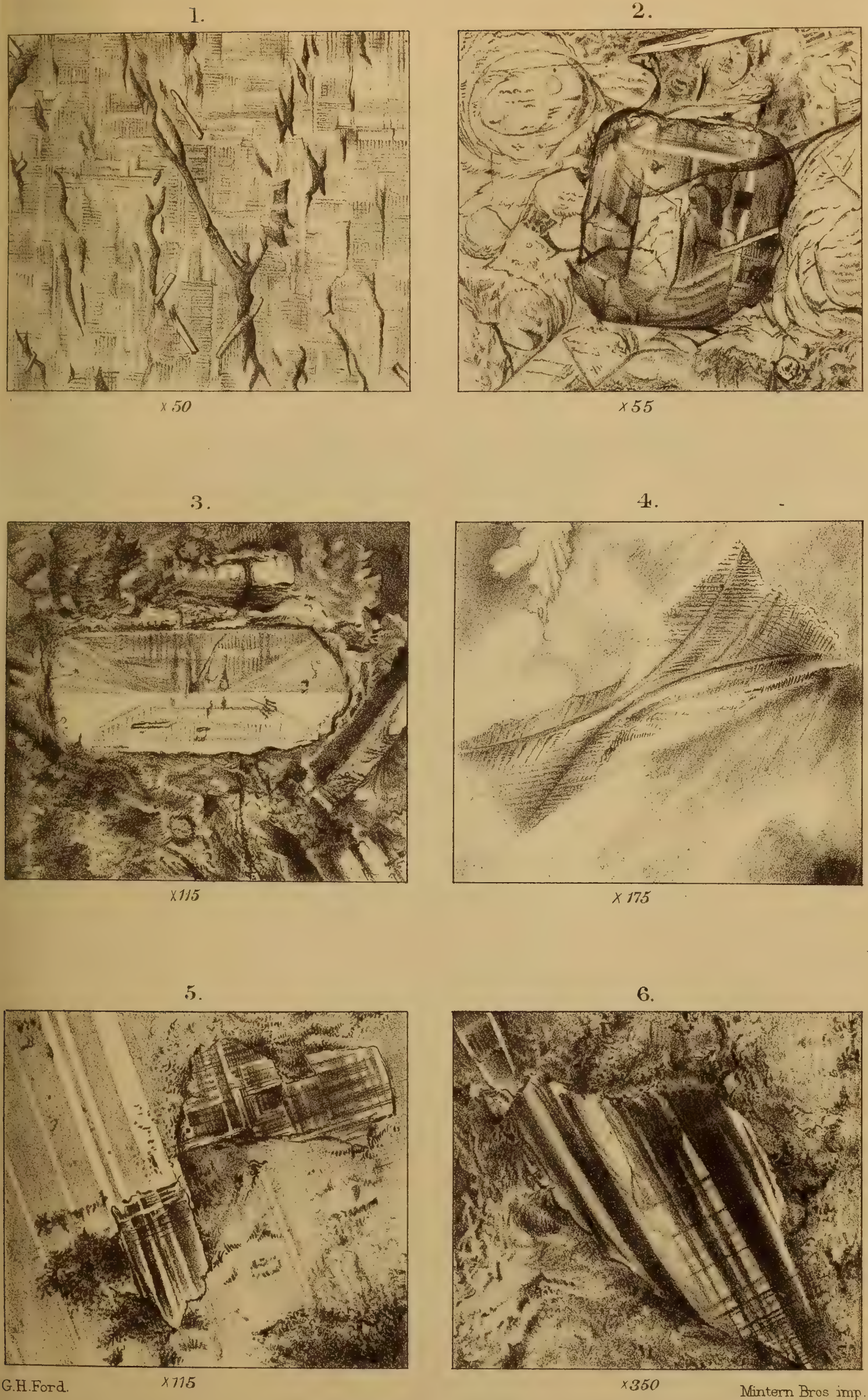
11. Diagrammatic section similar to fig. 10, but cut more obliquely to the twinning-planes, so that, instead of coloured bands separated by light or dark ones, an unbroken surface of white light might result, although the section might be that of a felspar many times twinned.

DISCUSSION.

Mr. KOCH thought that the structure of the crystals depended greatly upon the manner in which the rock was formed and the treatment which it had subsequently undergone. Exposure to high temperatures will cause the angles of crystals to alter greatly; and he had thought that felspars might be used as pyrometers for this reason, but on trying the experiment found that various changes in the angles were produced by exposure to the same temperature. He noticed that crystals formed in the humid way, heated and suddenly cooled, will present exceptional forms. He could not understand the curved lines shown in the crystal from Mexican obsidian.

Mr. Forbes considered that, although the so-called twin stripes or striæ seen on the cleavage-planes of many felspars were evidence of their being triclinic, when regarded as a means for discriminating felspars, too much importance is often attached to the striation and cross-hatching seen under the microscope. In an inquiry like this, the first point, he thought, should be to secure for examination and comparison specimens of the different felspars of undoubted purity; and he laid the more stress on this, as a previous acquaintance with the orthoclase felspars from Twedestrand, Arendal, and Ytterby, specimens of which the author now exhibited and described, made him believe them to contain an admixture of oligoclase, disposed in the same manner as the Perthite of Canada, which is an admixture of orthoclase and albite, a similar arrangement being perceptible even to the naked eye in the specimens exhibited; and he therefore could not regard conclusions drawn from the examination of such specimens as altogether to be depended on.

Mr. Rutley briefly responded, pointing out that not merely curved but rectilinear internal boundaries, or divisional markings, occurred in crystals developed in the same fragment of obsidian. He admitted to some extent the justice of Mr. David Forbes's remarks, but was not prepared to agree with him on the worthlessness of the microscopic observation of twinning and striation *as a rule*; and he considered that if Mr. Forbes's assumption were true, the diagnosis of many eruptive rocks, by ordinary microscopic examination, would become an almost impossible task.



1. x 50

2. x 55

3. x 115

4. x 175

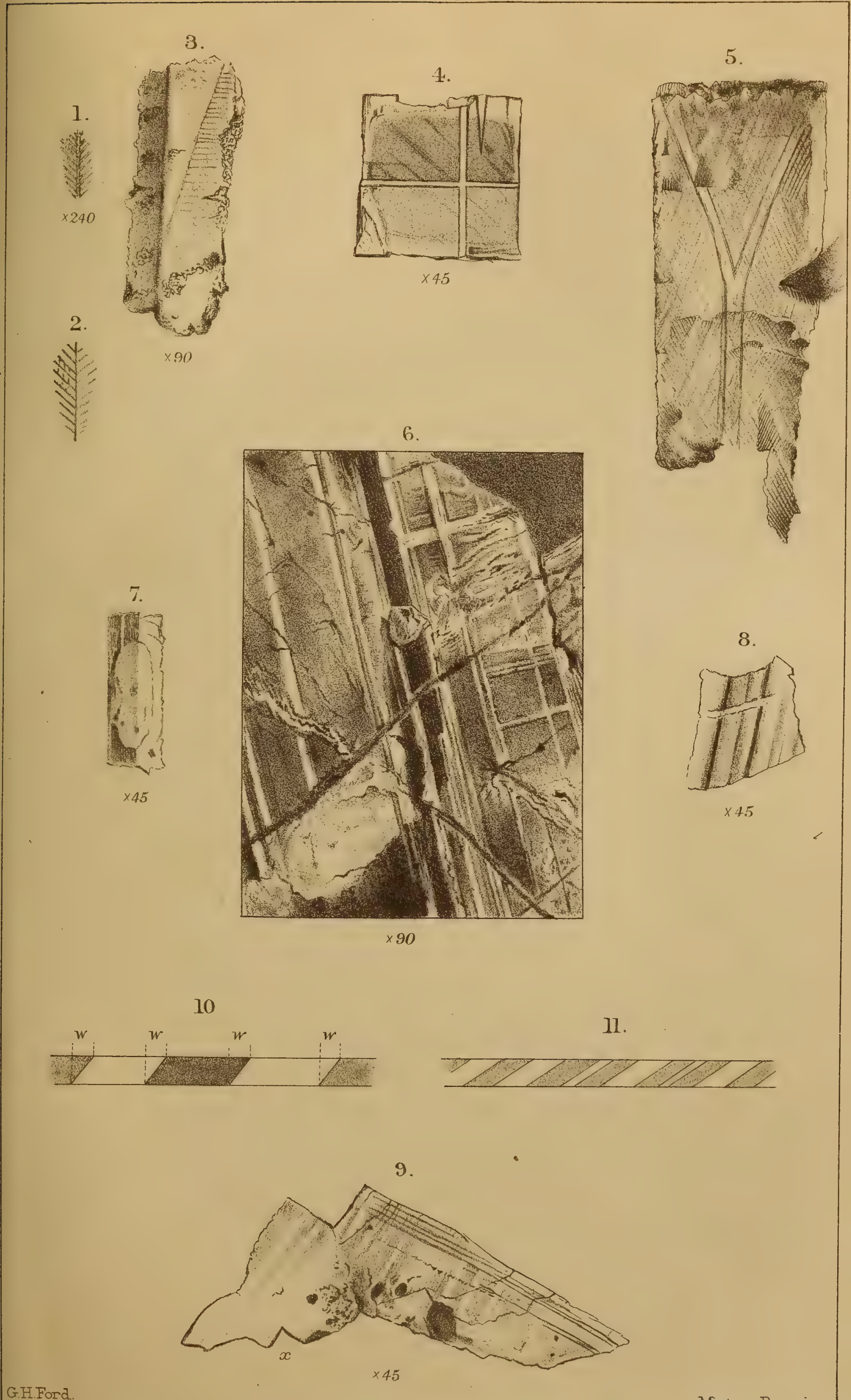
5. x 115

6. x 350

G.H.Ford.

Mintern Bros imp.

FELSPAR SECTIONS.



G. H. Ford.

Mintern Bros. imp.

FELSPAR SECTIONS.

36. NOTES *on the* BINGERA DIAMOND-FIELD, *with* NOTES *on the* MUDGEE DIAMOND-FIELD. By ARCHIBALD LIVERSIDGE, Esq., F.G.S., Reader in Geology and Mineralogy, University of Sydney. (Read June 24, 1874.)

[Abridged *.]

THE first announcement of the occurrence of the diamond in Australia was made by the Rev. W. B. Clarke, F.G.S., in 1860. Specimens were found, in 1852, at Calula Creek, and, in 1859, near Sutton's Bar, in the Macquarie river, at Burrendong, and at Pyramul Creek.

In 1867 diamonds were discovered by gold-diggers in the Mudgee district on the Cudgegong river, which flows into the Macquarie. In 1869 they were worked pretty extensively at this spot; and in 1870 Mr. Norman Taylor and Dr. Thomson described the Mudgee diamond-field in a paper read before the Royal Society of New South Wales. From this it appears that the diamond-bearing spots lie along the river in outliers of an old river-drift, at varying distances from the river and at an elevation of 40 feet or more above it. The outliers are capped by deposits of hard and compact, sometimes columnar basalt, regarded by Mr. Taylor as of older Pliocene age. These outliers, with their basaltic capping, may be traced for about seventeen miles up the river; in some of them the diamantiferous drift is still 70 feet in thickness.

The outliers which have been worked are enumerated by Messrs. Taylor and Thomson as follows:—Jordan's Hill, 40 acres; Two Mile Flat, 70 acres; Rocky Ridge, 40 acres; Horse-shoe Bend, 20 acres; and Hassall's Hill, 340 acres: in all, 510 acres. The drift has invariably been met with in these localities on tunnelling under or sinking through the basalt. In one patch a peculiar deposit of crystalline cinnabar was met with.

No diamonds have been found in the river-bed, except where the diggers have discharged their tailings into the river, or where gold has been washed.

The basalt, when not resting upon the drift, frequently lies upon metamorphic shales, slates, sandstones, or greenstone. The general formation of the country is regarded as Upper Silurian, with overlying outliers of Carboniferous rocks. The rocks in the vicinity are nearly vertical, with a general N.N.W. strike, and consist of red and yellow coarse- and fine-grained indurated sandstones, thin white argillaceous shales, pink and brown fine-grained sandstones with purple stripes, slates and hard metamorphic schists, hard brecciated conglomerate with limestone nodules, flint and red felspar in a

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* [As this paper is to a great extent identical with one communicated by the author to the Royal Society of New South Wales in October 1873, and published in their 'Proceedings,' it is here given only in abstract.—ED. Q. J. G. S.]

greenish siliceous base, and dykes and ejections of intrusive greenstone. The rocks are generally devoid of mica.

The older Pliocene diamantiferous drift is generally coarse and loose, but in parts cemented together by a white siliceous cement, sometimes green by admixture with silicate of iron; sometimes oxides of iron and manganese are the agglutinating agents. Diamonds were found in this solid portion.

The drift consists chiefly of boulders and pebbles of quartz, jasper, agate, quartzite, flint, slate, shale, and sandstone, with coarse sand and clay. The quartz-pebbles are often incrusted with oxide of iron or manganese. Many of the boulders and pebbles show a peculiar brilliant polish or glaze, not due to friction, since the cavities are equally well polished. Silicified wood is common; and coal has been found in the river higher up—also Carboniferous fossils, such as *Favosites gotlandica*, and *Orthis*.

The minerals associated with the diamond are:—1, black vesicular pleonast; 2, topaz; 3, quartz; 4, corundum; 5, zircon; 6, tourmaline; 7, black titaniferous iron-sand; 8, black magnetic iron-sand; 9, brookite; 10, wood-tin; 11, garnet; 12, iron, from tools; 13, gold.

The diamonds are distributed sparingly and irregularly through the older Pliocene drift. The average weight of the diamonds was 0·23 carat or nearly 1 carat grain. The largest discovered was a colourless octahedron of 5$\frac{5}{8}$ carats. Average sp. gr. 3·44.

The newer Pliocene drift also furnishes a few diamonds; and, being chiefly derived from the older drift, it contains the same minerals; but a few grains of osmiridium are also found in it.

A few diamonds have also been found in Victoria.

The Bingera Diamond-field.

The workings are about seven or eight miles south of Bingera, and are situated in a basin-shaped valley among the mountains of the Drummond range. This valley is about four miles long, and three miles broad, and opens to the south. The surrounding district is of Carboniferous or Devonian age. The valley seems to have been covered by diamantiferous drift; but much of this has been removed by denudation, leaving patches. Running into the basin are spurs of basalt, which also probably overlies the drift.

The bed-rock under the drift is an argillaceous shale. Blocks of this are scattered through the lower part of the drift; and small outcrops of it are seen in one or two places. In some parts there are outcrops of a siliceous conglomerate composed of subangular pebbles with ferruginous cement, sometimes replaced by manganese; and the junction of the conglomerate with the shale is shown by a small gully. The rocks are much contorted and almost vertical. Diamonds occur in the surface soil over the conglomerate here, but not over the shale.

All the workings for diamonds are confined to the surface, the drift not being removed to a greater depth than 2 or 3 feet. The author describes the process adopted, which he thinks must cause the loss of many diamouds. He also mentions the average number of diamonds per load of drift obtained in certain workings.

The Drift.—The characters of the diamantiferous drift of the Bingera diamond-field are as follows:—On the surface there are boulders and large pebbles of various kinds, principally siliceous, and elongated pebbles of a very fissile argillaceous sandstone, the smaller of which are termed "finger-stones" by the miners, and regarded as a favourable sign. Blocks of very compact conglomerate occur among the other rolled stones; the smaller pebbles in this are generally subangular.

The drift itself is largely composed of clay and sand. The clay shows a brecciated structure, as if recently derived from a comminuted shale; and parts of it, when freshly dug out, are of a bright green colour, probably due to ferrous silicate, as it becomes pale brown on exposure. Large blocks of the bed-rock are found in the drift. Minute crystals of selenite occur in the clay.

The larger pebbles include rolled white quartz (apparently vein-quartz), red, green, brown, black, yellow, and veined jasper, a little cacholong, black flinty slate, concretions of limonite, generally spherical (occasionally imbedded in rolled masses of magnetite, within which the nodules seem to have formed by segregation of iron oxide), botryoidal carbonate of iron, rolled masses of very soft shale, and a little petrified wood. The pebbles are not glazed as in the Cudgegong deposits.

The residue left after the puddling process consists of sand and small pebbles, and is known as "gem sand." It is from this that the diamonds are picked out. Associated with the diamonds in it are the following minerals:—

1. Topaz, generally rolled and water-worn, colourless and transparent, sometimes greenish. 2. Corundum, usually in small angular blue and green fragments. 3. Quartz, as rolled pebbles and worn crystals, also jasper and small black pebbles of flinty slate, the presence of which is regarded as a good sign by the miners. Small jaspery pebbles, usually measuring about $\frac{1}{3}$ in. by $\frac{1}{8}$ in., showing light mottled tints of drab, yellow, brown, pink, &c., and pretty highly polished, are known as "morlops" by the miners, and regarded as furnishing favourable indications. 4. Tourmaline, in rolled black crystals about $\frac{1}{2}$ inch long. 5. Spinel, of a dull red or pinkish colour, often much broken. 6. Zircon, in small rolled fragments and crystals, colourless, red or brown. 7. Wood-tin, rare, in small rolled pieces. 8. Ilmenite, not common. 9. Brookite, rare, in flat, rolled, translucent plates. 10. Magnetic iron-sand, in minute brown grains, sometimes showing octahedral form under the microscope, strongly magnetic. 11. Garnet, in small, ill-formed reddish-brown crystals, not very common. 12. Gold, rather scarce, usually in very thin spangles, generally attached to the magnetite. 13. Osmiridium, rare, in small, flat, heavy plates.

The diamonds are generally small, and the crystals not particucularly well developed; the faces are usually much rounded. They vary from colourless to pale yellow and green. Their specific gravity is 3·42, that of the Mudgee diamonds being 3·44.

In all parts of the world where the diamond is found it seems to occur in sandstone regions, associated with basaltic rocks, and usually in a drift or conglomerate. This statement applies to India, Russia, Borneo, Brazil, and Africa. The true source of the diamond has evidently not yet been ascertained; for in all the cases mentioned the sources may be regarded as secondary.

37. *On the* Lias *about* Radstock. By Ralph Tate, Esq., Assoc. Linn. Soc., F.G.S., &c. (Read May 26, 1875.)

A recent writer* states that the geological history of Somersetshire has yet to be written; if this be true (and it is not for me to decide), what a marvellous tale will have to be told! if we may judge from the deeply interesting portions of that history already made known to us by Mr. C. Moore, some of the results of whose labours, which cover many years, are embodied in two communications to this Society†, and are illustrated by a most extensive and exquisite suite of fossils deposited in the Bath Museum.

Without seeking to disparage the larger views set forth in the last-mentioned papers, yet I consider a modified interpretation of some of the phenomena is required; and calling to my aid an extended acquaintance with Liassic species and their distribution, I believe that I am in position to give a more complete account of the sequence of deposits, so far as relates to the Liassic rocks in the neighbourhood of Radstock, than has yet been done.

Wherever the Lias has been critically studied, it is found that there is a parallelism in the succession of life, most especially in regard to the species of *Ammonites*—so much so that the strata admit of a grouping after their palæontological characteristics, and further into regions of *Ammonites*, a classification as much in harmony with facts as that of the Oolitic rocks into formations.

The recognized divisions of the Lower and Middle Lias are as follows:—

Middle Lias. Zones of *Ammonites spinatus*, *A. margaritatus*, *A. capricornus*, and *A. Jamesoni*; to the last are annexed an upper zone of *A. ibex* and a lower one of *A. armatus*.

Lower Lias. Zones of *A. oxynotus* (including the subzones of *A. raricostatus*, *A. oxynotus*, and *A. obtusus*), *A. Bucklandi*, *A. angulatus*, and *A. planorbis*, with the *Ostrea-liassica* beds and the White Lias.

Mr. Moore has given sections of the Liassic rocks centering in Radstock, which may be summarized as follows:—

Middle Lias	Marlstone	15 feet thick.
Lower Lias	*A.-raricostatus* beds Grey Lias or *Bucklandi* series	16 „ „
White Lias series		8 „ „

Herein the zones of *A. angulatus* and *A. planorbis* are unrecognized, and the medio-Liassic portion is not correlated; nevertheless I find no other than the normal arrangement to obtain.

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* H. B. Woodward, Proc. Somersetshire Nat.-Hist. Soc., vol. xix. 1873.

† Quart. Journ. Geol. Soc. vols. x. and xxiii.

The Lower Lias is reduced in this district to 24 feet, as contrasted with the 300 feet or more assigned to it in other areas: this is due either to attenuation of its subdivisions or to denudation of a portion; and though both causes seem to have played a part, yet it is to poverty of sediment that I ascribe the first consideration. If this be so, then it must be conceded that the zones of *Ammonites* are consequently compressed, and that species are brought into so near superposition as to be almost in juxtaposition. But, so long as they are superimposed, the order is uncontroverted, and it would be escaping from conviction to declare them to be mingled together. I dare assert that the succession of Ammonite-life is as much *en règle* in the Radstock Lias as in the most typical districts, though the contrary has been maintained. This being the case, there is no need to discuss the question as to whether or not the absence of a zone constitutes a proof of unconformability, as it has been supposed to do upon wrong premises in so far as relates to this district*.

Attempts have been made to invalidate the importance of zoological zones over a wide area, though it is generally admitted that they are applicable to special localities. In the criticisms that have been called forth adverse to the law of succession, minor considerations have been allowed to outweigh the generalizations of a larger experience, and the critics have based their arguments more frequently than otherwise on faulty observations. Incorrect identification of species and inferring the position of fossils from their matrices are the chief sources of error. When *Ammonites Charmassei* is confounded with *A. angulatus*, then the range of the latter is greatly elevated; when *A. Sauzeanus* is called *A. spinatus*, then that species is made to traverse the whole of the Middle Lias and a great part of the Lower Lias; when *A. fimbriatus* is recorded as *A. cornucopiæ*, then an associate of *A. communis* is seen in company with *A. Jamesoni*. Notices of similar mistakes might be multiplied; but I have given sufficient to show upon what unstable foundations are based some of the arguments of the opponents to the docrine of zoological zones. The practical value of a knowledge of the distribution of species in the Lias has been recognized in the Cleveland district.

LOWER LIAS.

I will now give the Radstock section of the Lower Lias by way of illustrating my opinion regarding its subordinate groups.

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* Moore, Quart. Journ. Geol. Soc. vol. xxii. pp. 459, &c. Woodward and Blake, Geol. Mag. vol. ix. p. 198.

Section, Old Pit Quarry near Radstock.

Note. The Italic characters prefixed to the strata in the several sections indicate that they are identical or correlative.

	No. of bed.	Description of strata.	Thickness.	
			ft.	in.
	6.	Conglomerate base of the Middle Lias.		
Zone of *A. oxynotus*	7. (*d*)	Blue clay		3
	8. (*e*)	Black-blue gritty limestone (weathering russet-coloured). Fish-scales, *Ammonites subplanicosta,* Oppel, *Waldheimia sarthacensis*		4
	9. (*f*)	Layer of brown hæmatite pebbles in sandy clay, of variable thickness, filling irregularities of surface of	1	10
	10. (*f*)	Black clay, irregularly bedded		
Zone of *A. Bucklandi.*	11. (*g*)	Sandy layer, with black nodules, full of *Spiriferina Walcotti*		6
	12. (*h*)	Pepper-and-salt-coloured gritty limestone in two blocks. *Spiriferina, Rhynchonellæ, Pecten Thiollierei,* &c.	1	1
Zone of *A. angulatus* and *A. planorbis.*	13.	Gritty limestone		4
	14. (*i*)	Id. *Lima gigantea, Ostrea arcuata*	1	6
	15.	Id.		5
	16.	Id.		9
	17.	Id.		6
	18.	Blue gritty limestones	4	7
	19.	Blue limestone. *Amm. Johnstoni, Lima gigantea*		11
	20.	Id.		7
	21.	Id.		3
	22.	Ten beds of blue limestones	5	5

The beds known as the "Grey Lias," embracing beds Nos. 22–13 of the foregoing section, have been placed by Mr. Moore on the horizon of *Ammonites Bucklandi*; and that author asserts that the two lower zones of *A. angulatus* and *A. planorbis* are altogether wanting. Though I have not worked long enough at these beds to arrive at a full decision as regards the whole mass, yet from the partial palæontological facts obtained and a *coup d'œil,* I have no hesitation in referring a considerable portion of them to the *A.-angulatus* and *A.-planorbis* series. *Ammonites Johnstoni,* which invariably occurs in the lower *A.-angulatus* beds and on the confines of the *A.-angulatus* and *A.-planorbis* zones, is present in the middle part of the "Grey Lias" beds. Its position is given in the above section; whilst in a quarry on the Wells road I have found *Ammonites planorbis,* with *Pholadomya glabra, Pinna Hartmanni, Lima hettangiensis,* and *Ostrea semiplicata,* in lower beds, which in their turn are underlain by flaggy limestones or "firestones" the surfaces of which are crowded with *Ostrea liassica.*

As we pass upwards in the Radstock section, the limestones gradually acquire a more and more siliceous property, which reaches a maximum in the bed No. 12. This highly fossiliferous stratum, and the overlying sandy beds, are undoubtedly on the horizon of *A. Bucklandi,* as they contain the dominant Ammonite and a few of its common associates in the upper portion of the zone—*A. obliquecostatus*, Ziet., *A. Sauzeanus*, D'Orb., *A. Scipionanus*, D'Orb., and *Belemnites infundibulum*, Phillips.

The question how much of the Grey Lias should be apportioned to the *Bucklandi* series seems at first difficult to answer, because of the gradual change in property of the limestones, and their apparently unfossiliferous character. The thick limestone immediately underlying the *Spiriferina* bank in the Radstock section contains *Ammonites Bucklandi* and the ordinary fossils of the zone; it is a constant feature throughout the district. The underlying limestone, about equal in thickness to the other, has yielded *Ammonites Johnstoni* and *A. angulatus* at several places, see Medyeat and Tyning sections.

Section, Medyeat Quarry, 1 mile N. from Camerton.

Zones		ft.	in.
A. oxynotus.	(*e*) Thin stone band		2
	(*f*) Blue clay, no bedding	7 to 8	0 0
A. Bucklandi.	(*g*) *Spiriferina*-bed		4
	(*h*) Blue limestone	1	1
	Clay parting		3
A. angulatus.	(*i*) Bluish limestone. *Ammonites angulatus*, *A. Johnstoni*, *Eucyclus elegans*, *Macrodon hettangiensis*, &c.	1	0
	Six thin limestones. *A. Johnstoni*, *Lima gigantea*, &c.	3	2

It is therefore expedient to regard the upper limestone and its overlying *Spiriferina* bank as belonging to the *Bucklandi* zone, and the inferior beds of the Lower Lias as one palæontological member, in which, however, *Ammonites angulatus* and *A. Johnstoni*, *A. planorbis* and *Ostrea liassica* have their customary relative positions. Consequently the greater bulk of the Lower Lias limestones in this district belong to the Infra-Lias, as is the case in the Bristol area, where the whole series acquires a very considerable development, and the *Bucklandi* beds are comparatively insignificant, the so-called *Lima* beds being really part of the *A.-angulatus* and *A.-planorbis* zones.

Though the limestones preserve a pretty general character throughout the Radstock area, yet a comparison of the following section at Clan Down with that of the Old Pit Quarry, Radstock, half a mile distant, will show that the series does exhibit sudden changes. Here the *Spiriferina* bank is still recognizable, and makes a good stratigraphical line; at Tyning Quarry it is reduced to a minimum, but both the lithological and palæontological characteristics are preserved.

Section, Quarry near Clan-Down Colliery.

No. of bed.	Description of strata.	Thickness. ft.	in.
6. (*b*)	Conglomeratic base of the Middle Lias.		
7. (*f*)	Dark clay (No. 10, Radstock section) having as a base a		10
8. (*g*)	Sandy layer with quartz pebbles and phosphatic nodules. *Spiriferina Walcotti*, *Ammonites obliquecostatus.*		
9. (*h*)	Yellowish subcrystalline gritty limestone. *Ostrea arcuata*, *Cidaris Edwardsii*		1½
10.	Cream-coloured earthy limestone	1	2
11.	Laminated calcareous sandy shale		2
12.	Reddish yellow subcrystalline limestone in 2 blocks. *Pleurotomaria similis*, *Astarte obsoleta*, Dunker, *Ostrea arcuata.*		7
13.	Grey, splintery, hard limestone		10
14.	Rubbly limestone		8
15.	Soft, white, fine-grained limestones	3	6

The fossils of the *Spiriferina* bank are :—

Strophodus, sp.
Ammonites Bucklandi, *Sow.*
—— Conybearei, *Sow.*
—— Sauzeanus, *D' Orb.*
—— Scipionanus, *D' Orb.*
—— obliquecostatus, *Zieten.*
*Lima hettangiensis, *Terq.*
—— gigantea, *Sow.*
—— pectinoides, *Sow.*
*—— succincta, *Schloth.*
*Pinna Hartmanni, *Schloth.*
Pholadomya glabra, *Agassiz.*
—— ventricosa, *Ag.*
Nautilus striatus, *Sow.*
Belemnites infundibulum, *Phill.*
—— grandævus, *teste Phillips.*
Cryptænia solarioides, *Sow.*
Cerithium verrucosum, *Terq.* ?
Ostrea arcuata, *Lamk.*
Pecten calvus, *Goldf.*
—— Thiollierei, *Dumort.*
—— textorius, *Schloth.*
Unicardium cardioides, *Phillips.*
*Cardinia Listeri, *Sow.*
Pleuromya crassa, *Ag.*
—— liasina, *Schloth.*
Waldheimia sarthacensis, *D' Orb.*
Terebratula punctata.
Rhynchonella plicatissima, *Quenst.*
—— variabilis, *Schloth.*
Spiriferina Walcotti, *Sow.*
*—— rostrata.
Neurofungia mammillata, *De From.*
Proboscina, sp.
Myoconcha oxynoti, *Quenst.* (Bath Mus.)

Ammonites-oxynotus *Series.*—The Foraminiferal clay (No. 10 Radstock section) which overlies the *Spiriferina* bank, exhibits at Radstock no decided stratification, but indicates rather a heaping together of the mass and not tranquil deposition; its upper surface is irregular, but somewhat levelled up by an accumulation of a ferruginous gravel in its depressions. At Medyeat, north of Camerton, the clay is similarly a confused mass with an undulating upper surface, strongly marked by the waving course of a thin limestone cover. In the Bowldish and Timsbury sections this clay is regularly bedded; and in each we attain to a higher level in the *Oxynotus* beds than in the other sections. The variation in thickness of the Foraminiferal clay within a few square miles is remarkably great; at Medyeat it is from 7 to 8 feet, at Timsbury 5 feet, at Bowldish 2 feet 2 inches, at Radstock 1 foot 10 inches, at Clan Down 10 inches, probably reduced

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* Collected by Mr. Tawney.

by denudation before deposition of Middle Lias; and at Phyllis Hill, south of Paulton, and at Munger, it is absent.

The true character of the *Oxynotus* series may be determined from the two following sections:—

_Bowldish_*.	ft.	in.	_Timsbury_†.	ft.	in.
1. Soil.			Soil and disturbed clay.		
2. (*b*) Middle Lias limestone, hard and flaggy, with lumps of *A.-raricostatus* stone and derived nodules. *Ammonites Ægion*, *A. armatus*, *A. Buvignieri*, &c.		9	Absent.		
3. (*c*) Blue, fine-grained, argillaceous limestone in oblong masses, rounded margins, and irregular surfaces. *A. raricostatus*, *Belemnites acutus*, &c.		4	(*c*) Blue subcrystalline limestone course. *A. obtusus*, *A. planicostatus*, *A. xiphus*		4
4. (*d*) Brown clay, speckled with white calcareous particles. *B. acutus*		9	(*d*) Shaly clay, red or brown on weathered edges	2	4
5. (*e*) Limestone course, equivalent to No. 8, Old-Pit Quarry, Radstock. *A. planicostatus*, *Monotis inæquivalvis*, *Pecten calvus*; Fish.		5	(*e*) Marly band, with *Belemnites acutus*		2
6. (*f*) Black clay, with small limestone concretions and cinder-like lumps of phosphatic matter at the base	2	2	(*f*) Black shaly clay. *A. planicostatus* and numerous small bivalves	5	0
	3	8		7	10
7. (*g*) *Spiriferina* bank.			(*g*) *Spiriferina* bank.		

Fossils from the Zone of Ammonites oxynotus, *Radstock District.*

Ammonites raricostatus, *Sow.*; Bowldish, *in situ*; in other localities in derived nodules.
—— planicostatus, *Sow.*; Radstock, Bowldish, Timsbury.
—— xiphus, *Ziet.*; Timsbury (E. B. Tawney).
—— obtusus, *Sow.*; Timsbury and Phyllis Hill (E. B. Tawney).
—— oxynotus, *Quenst.*? Timsbury (E. B. Tawney).
Belemnites acutus, *Miller*; Timsbury, Bowldish.
Eucyclus selectus, *Chap. & Dew.*; Bowldish.
Lima pectinoides, *Sow.*; Bowldish.
—— gigantea (juv.), *Sow.*; Timsbury.
Nucula navis, *Piette*; Timsbury.
Leda galathea *D'Orb.*; Timsbury.
Lucina limbata, *Terq. & P.*; Timsbury.

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* The Bowldish Quarry is at the junction of the road running due north from Welton with that from Munger to Clan Down.

† The Timsbury Quarry is below the village of that name, and is adjacent to the New Conygre Colliery; the two quarries are 1¾ mile apart.

Monotis inæquivalvis, *Sow.*; Bowldish; Timsbury (E. B. Tawney).
Pecten textorius, *Schloth.*; Phyllis Hill (E. B. Tawney).
—— calvus, *Goldf.*; Bowldish.
Ostrea arcuata, *Lamk.*; Bowldish.
Waldheimia sarthacensis, *D'Orb.*; Bowldish.
Rhynchonella variabilis, *Schloth.*; Bowldish.
—— plicatissima, *Quenst.*; Bowldish.
Ditrypa quinquesulcata, *Goldf.*; Bowldish.
Serpula deplexa, *Phillips*; Bowldish.
Foraminifera.

MIDDLE LIAS.

This formation is introduced by a conglomerate bed consisting of a black limestone breccia and conglomerate, and forming at Camerton and Clan Down a separate bed, but at Radstock, Bowldish, and Munger entangled in the yellow limestone constituting the so-called *marlstone*. These derived fragments of stone yield *Ammonites raricostatus*; and associated with them are rolled or broken casts of that fossil, as well as of *Ammonites obliquecostatus* and *Pleuromya crassa*. The yellow matrix in which they are imbedded contains *Ammonites armatus*, *A. Ægion*, and *A. Taylori*. Here, undoubtedly, we have a commingling of Ammonites of different horizons; but in this case an explanation of the association is easy, inasmuch as the upper beds of the Lower Lias have suffered denudation, even over the present tracts; probably much of the strata so removed were clays containing limestone nodules and casts of shells in the same material, and out of which they have been washed and subsequently cemented by the mid-Liassic ooze. At Clan Down the Foraminiferal clay was partially involved in the denudation; and at Munger the whole of it was removed.

Thus, it seems to me that continuous and tranquil deposition went on in this district from the commencement of the Lias period until the accumulation of the *Spiriferina* bank, that through some change of currents there was a hurried or disturbed deposition of the Foraminiferal clay over certain areas, succeeded by a more normal condition, during which 2½ feet of strata at least were accumulated; but how much more can only be known by the discovery of beds in this area which will conduct us from the band with *A. planicostatus* to the yellow limestone with *A. armatus* without a stratigraphical break. Then there follows a most decided physical unconformity, marked by the remanié fossils of the *oxynotus* beds and their entire removal over certain spots.

The so-called *marlstone* is mainly a yellow ironshot limestone of a maximum thickness of 13 feet, and so much resembles some members of the Inferior Oolite that it is only after recognition of the fossils that one is prepared to admit its Liassic age.

The following sections will convey the leading palæontological and lithological features of this interesting rock-group:—

Section, Old-Pit Quarry, Radstock.

No. of bed.	Description of strata.	Thickness. ft.	in.
1.	Soil.		
2.	(*a*) Dense, black, splintering limestone, flaggy at top—*Ammonites ibex, A. fimbriatus*; yellow and ironshot below—*A. latecostatus, Nautilus intermedius*	3	0
3.	(*a*) Hard, yellowish grey, ironshot limestone, somewhat lumpy. *A. Jamesoni*	7	0
4.	(*a*) Soft, yellow, ironshot limestone	1	6
5.	(*a*) Brown, laminated, calcareous shale, full of Belemnites and Palliobranchs		8
6*a*. 6*b*.	(*b*) Yellow ironshot limestone, Id., with derived nodules, } one block		10
		13	0

Section, Munger Quarry, near Paulton.

Is distant about 2 miles from Welton Station on the Bristol and Radstock Railway, and may be reached by following the by-road on the right on gaining the turnpike-road to Paulton.

No.	Description of strata.	Thickness. ft.	in.
1.	Soil.		
2.	(*a*) Blue limestone, very hard and splintery, weathering grey and splitting into thin slabs. *Ammonites ibex, A. fimbriatus, A. latecostatus*, many Belemnites, *Cryptænia expansa, Phasianella turbinata, Rhynchonella furcillata*	1	0
3.	(*a*) Hard, yellowish grey, ironshot limestone. *A. ibex, Cryptænia expansa, Inoceramus ventricosus, Pecten lunularis*	1	5
4.	(*a*) Similar to, but softer than No. 3, in two blocks. *A. ibex, A. latecostatus, Nautilus intermedius*, many Gasteropods, *Ostrea semiplicata*	2	0
5.	(*a*) Soft, yellow, ironshot limestone, bedding indistinct, rather lumpy, disposed on the quarry-face. Fossils exceedingly numerous and easy of extraction: *A. Jamesoni, A. brevispinus, A. polymorphus, Pinna folium*, &c.	5	0
	Clay parting		
6.	(*b*) Mixed bed; matrix a yellow ironshot limestone, enclosing lumps of blue fine-grained limestone, and black irregular-shaped nodules of limestones derived from the Lower Lias		6
		9	11

Section, Quarry on Clan Down near Radstock.

1.	Soil.			
2.	(*a*) Rubbly limestone, displaced *in situ*	No. 5 at Munger	3	0
3.	(*a*) Yellow ironshot limestone		2	0
4.	(*a*) Brownish clay			
5.	(*b*) Yellowish grey ironshot limestone with black nodular lumps. *A. Tylori, A. armatus, Trochus limbatus, Chemnitzia Blainvillei, Phasianella turbinata, Ostrea obliquata, Rhynchonella variabilis, Ditrypa etalense*, and other species of the higher beds	=No. 6 at Munger, and Nos. 6*a* and 6*b* at Radstock.		7
6.	(*b*) Blue limestone nodules			4

A departure from the usual character of this limestone is exhibited by a quarry-section near Tyning, about ½ a mile west from Timsbury. Here the Middle Lias is represented by a whitish marly limestone, in some parts fissile, and like some White Lias and *Ostrea-liassica* beds in other portions; it is similar to chalk-marl. It has no conglomerate below, which so largely prevails throughout the Radstock district, but rests on the denuded surface of the Foraminiferal clay, which varies from 3 to 24 inches in thickness. The section is as follows:—

		ft.	in.
Middle Lias:			
1. (*a* & *b*)	White marly limestone, full of Belemnites, *Ammonites Buvignieri*, *A. Jamesoni*, *Bel. clavatus*, *B. elongatus*, *Pitonillus conicus*, *Trochus Thetis*, *Spiriferina rostrata*, *Waldheimia cornuta*, &c.	2	6
Lower Lias:			
2. (*f*)	Brown clay.	2	0 to 4
3. (*g*)	*Spiriferina*-bank, hardly recognizable, much phosphatic matter.		
4. (*h*)	Grey limestone with a dense phosphatic layer at top. *A. Bucklandi*	1	3
5.	Clay parting		3
6. (*i*)	Hard grey limestone. *A. Johnstoni*		
7.	Similar limestones.		

The distribution of the Ammonites, as well as the presence of certain other mollusks, proves that the whole thickness of the yellow limestone of Radstock belongs to the *A.-Jamesoni* series, and that the subordinate divisions, characterized by *A. armatus*, *A. Jamesoni*, and *A. ibex*, are as clearly marked within the 13 feet as they are in the 150 feet which they occupy on the Yorkshire coast.

Mr. C. Moore was so sagacious as to perceive that the deposition of this rock was not synchronous with that of the so-called marlstone of Gloucestershire; he writes[*]:—"There appears to be little doubt the marlstone of this district occupies a different horizon from that at Ilminster, which is unquestionably the uppermost in the Middle-Lias series, whilst *probably* the former is at the very base of the series, and represents the passage beds of the Lower into the Middle Lias." Though a very decided opinion is here expressed, yet he elsewhere wavers; and as some errors of determination have given a show of discordance in respect to the persistency of Ammonite-zones, there seemed to be grounds for a revision of the whole facts.

The revised map of the district, issued by the Geological Survey in 1871, indicates Lower Lias only over the area occupied by the *A.-Jamesoni* limestones; and as it would have been so contrary to custom to represent a "marlstone" as a Lower Lias, I wrote to Mr. H. B. Woodward, who assisted in the survey, for an explanation, which is as follows:—"The Middle Lias was omitted because the small scale of the map did not allow of its being shown." Many species from this rock are referred, in the Catalogue of Fossils, Geological Survey Museum, to the Middle Lias, whilst the equivalent beds in Gloucestershire and Warwickshire, which are clays, are mapped as Lower Lias.

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[*] M. and U. Lias, S.W. of England, p. 38.

As these limestones are on the horizon of the brick-clays and "yellow lias" of Cheltenham, and of the shales forming the base of the North Cheek of Robin Hood's Bay, they cannot be correlated with the higher marlstone of Yorkshire, or with the still higher marlstone of Gloucestershire—circumstances which warrant the abandonment of the term marlstone as applied to a division of the Lias; and its employment as a lithological name is equally objectionable.

The common organic remains are mainly identical with those characterizing the lower beds of the Middle Lias on the Dorset and Cleveland coasts, at Cheltenham and Aston Magna in Gloucestershire, at Raasay and Pabba in the Hebrides, in N.W. Germany, in Würtemberg, and in the E. and S.E. parts of France, where the detailed distribution of the fossils has been worked out, their relation to higher and lower series made clear, and a remarkable uniformity of facies shown to obtain.

Local peculiarities are to be expected; and the Radstock representatives of the horizon are not without them. Elsewhere in the British Isles the *A.-Jamesoni* beds are chiefly argillaceous, and the ferro-calcareous nature is coordinated with the presence of restricted species, as in N.W. Germany where similar lithological features prevail the same palæontological peculiarity is present.

Among the prolific forms may be mentioned *Trochus Thetis*, **T. socconensis*, **Pitonillus conicus*, **Phasianella turbinata*, **Monodonta bullata*, **Turbo cyclostoma*, **Turbo Orion*, *Eucyclus Guadryanus*, **Cryptœnia expansa*, **C. heliciformis*, *Chemnitzia Blainvillei*, *C. undulata*, *Ostrea semiplicata*, *Pinna folium*, *Inoceramus ventricosus*, *Limea acuticosta*, **Pecten lunularis*, *Hinnites tumidus*, *Ostrea obliquata*, **Pholadomya ambigua*, *Waldheimia Waterhousei*, *W. indentata*, *W. numismalis*, *Terebratula punctata*, *Rhynchonella rimosa*, *R. variabilis*, **Ditrypa etalense*, and many of the Cephalopods. It is noteworthy, as illustrating the influence of the deposition of certain sediments upon the existence of particular specific forms, that many of the above species (marked with an asterisk) reappear in the ferro-calcareous rocks of the *A.-spinatus* beds, or in the limestones of the *A.-margaritatus* zone, and are absent more or less in the intervening clays. Despite these facts, a cosmopolitan fauna prevails; and the geographical distribution of its species seems to have been unaffected by any lateral change in the mineral condition of the depositing sediment; the trenchant lines occupied by the Ammonite-species must therefore be explained by some other cause.

Since the publication of a former paper†, in which I endeavoured to establish a palæontological break between the Lower and Middle Lias, new materials have been gathered, including some that are here appended, which prove a much greater hiatus to exist than was then demonstrated. Additional species in common have been admitted; but the gain of Middle-Lias forms in the *A.-Jamesoni* zone has considerably raised the percentage of the limiting species. In all localities where a succession is traceable the same general phenomena meet our view, namely a paucity of species in the *A.-oxynotus* series, and a sudden accession of new forms on entering

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† Quart. Journ. Geol. Soc. vol. xxvi.

the *A.-armatus* region. The series under review cannot even be regarded as passage-beds, as they are called by Mr. C. Moore. No traces of stratigraphical unconformity have, however, been noticed, save those described in this communication.

The strata intervening between the *A.-Jamesoni* limestone and the Oolite, estimated at 50 feet by Mr. C. Moore, are referred by that gentleman to the Upper Lias; but he does not give any facts in support of his view; the tract is coloured as Lower Lias on the Geological-Survey map. A clay-pit opened in the sloping ground between Munger Quarry and the Oolitic ridge to the north has not yielded any fossil evidence as to the position of the bed in the Liassic series. This is the only section in this stratigraphical horizon known to me. It is somewhat hazardous to speculate on the age of this imperfectly exposed stratum; but if viewed by the light afforded by neighbouring districts, it will seem more reasonable to regard it as belonging to the Middle Lias, and probably equivalent to the argillaceous beds of the *A.-capricornus* zone at Dundas, which are overlain by Inferior Oolite. Such an interpretation harmonizes with certain stratigraphical phenomena exhibited by the Middle Lias and Inferior Oolite about Frome, which indicate a cessation of deposit during Upper Lias times, and not of an unconformability between Middle and Upper Lias, which is demanded by Mr. C. Moore's proposition.

PALÆONTOLOGY OF THE JAMESONI BEDS IN THE RADSTOCK AREA.

The first published list of fossils from the yellow limestone of the Radstock district is in the 'Catalogue of Fossils of the Geological-Survey Museum,' 1865; to which numerous additions were made by Mr. C. Moore, in his 'Middle and Upper Lias of the S.W. of England,' 1867. I have examined many of the specimens upon which these lists are based, and others in the Bristol Museum, collected many years ago, and in Mr. Tawney's cabinet, and have, moreover, gathered a considerable number *in situ*. From these sources I have drawn up the following emended catalogue, in which I have recorded the actual numbers of specimens collected by myself during portions of four days at Munger, Clan Down, and Radstock, as affording the best estimate of the frequency of occurrence of the species. I have noted also the localities and areas in which the species have been obtained from the same horizon; these are indicated by the following capital letters, thus:—C.[*] Cheltenham; A.[†] Aston Magna; F.[‡] Fenny Compton; Y.[§] Yorkshire; D.[||] Dorset; H.[¶] Hebrides (Raasay and Pabba); G.[**] N.W. Germany; W.[††] Württemberg; R.[‡‡] Basin of the Rhone.

[*] [†] Tate, Quart. Journ. Geol. Soc. vol. xxvi.
[‡] Collections MM. Slatter and Beesley.
[§] Tate and Blake, Yorkshire Lias.
[||] Day, Quart. Journ. Geol. Soc. vol. xix.
[¶] Tate, Quart. Journ. Geol. Soc. vol. xxix.
[**] Brauns, Untere Jura.
[††] Oppel, Juraf.; Quenstedt, Jura.
[‡‡] Dumortier, 'Etudes Liasiques,' vol. iii.

Catalogue of Fossils from the A.-Jamesoni *zone in the Radstock District.*

Ichthyosaurus, sp., Camerton*; Clan Down.
Hybodus, sp., Camerton.
Nautilus intermedius *Sow.* (N. semistriatus (*Sow.*), *C. Moore*). Common at Munger and Radstock; Camerton. Y.
Ammonites Henleyi, *Sow.* (A. hybrida, *C. Moore*). Munger (*R. T.* and in Bristol Museum); Camerton. Y. C. D. G. W. R. F.
—— Maugenesti, *D'Orb.* Not rare. Munger, Radstock; Camerton. C. D. G. W. R. F.
—— fimbriatus, *Sow.* (A. lineatus and A. cornucopiæ, *C. Moore*). Common in the highest bed at Munger and Radstock. Y. C. D. G. W. R. F.
—— ibex, *Quenst.* (A. Boblayei, *D'Orb*). Very abundant in the higher beds, Munger and Radstock. C. D. G. W. F.
—— Jamesoni, *Sow.* (including A. Bronnii, *Röm.*). Common at Munger, Clan Down, and Radstock; also at Tyning. A. C. D. G. H. W. Y. R. F.
—— latecostatus, *Sow.* (A. maculatus, *C. Moore*). Not rare in the higher beds. Munger and Radstock. D. R.
—— Buvignieri, *D'Orb.* Several examples, Bowldish, Clan Down, Munger, Tyning.
—— pettos, *Quenst.* Two examples, Munger. C. D. G. W.
—— brevispinus, *Sow.* Three examples, Munger. C. D. G. W. Y. H. R. F.
—— polymorphus, *Quenst.* Three examples, Munger. Y. G. W.
—— armatus, *Sow.* Several examples, Radstock, Clan Down, Munger, *in situ*; in the rubble top, Wells Way Quarry; Bird's Hill (Geol. Surv.). A. C. D. G. H. F. W. Y. R.
—— Taylori, *Sow.* One example, Clan Down. D. G. W. Y.
—— aureus, *Simpson* (caprarius, *Quenst.*) Two examples, Munger. W. G. Y.
—— Ægion, *D'Orb.* (A. M'Donnellii, *Portlock*). Four examples, Radstock, Bowldish. Y. Antrim.
Belemnites clavatus, *Schloth.* Very common in all the localities. A. C. H. G. Y.

A monstrosity, possibly of this species, claims a notice; it may be described as a twin Belemnite. Externally it resembles a long narrow premolar tooth, one fang of which is longer than the other. The whole is 3 inches long, the two guards are soldered together through nearly their whole length; but the apical portions are free for $\frac{3}{4}$ of an inch; there is but one alveolar cavity (fig. 5, p. 507).

Belemnites acutus, *Miller.* Camerton. G.
—— longissimus. Clan Down. One example.
—— elongatus, *Miller.* Common at Radstock, Clan Down, and Munger; Tyning. G. C.
—— compressus, *Voltz.* Camerton (*C. Moore*).
—— breviformis, *Voltz.* Clan Down. F.
Dentalium elongatum, *Münster* (D. gracile, *Moore*). One example, Camerton. C.
—— compressum, *D'Orb.* (D. trigonalis, *Moore*). Two examples, Camerton; four examples, Radstock, Munger, and Clan Down.
—— liassicum, *Moore.* One example, Camerton; two examples, Munger.
Cryptænia expansa, *Sow.* (Helicina). Not uncommon in the highest beds, Radstock and Munger; Camerton, Tyning. C. G.
—— heliciformis, *Deslongchamps* (Pleurotomaria). Six examples, Munger.
—— affinis, n. sp. (see p. 507). Two examples, S. of Paulton (Geol. Surv.).
Pleurotomaria granosa, *Schloth.* (Trochus). Six examples, Munger.
—— anglica, *Sow.* Camerton. C.
Turbo cyclostoma, *Zeiten.* Twenty-nine examples, Munger, Clan Down. G.
—— Orion, *D'Orb.* Thirty examples, Munger; Clan Down.
—— socconensis, *D'Orb.* (Trochus pethertonensis, *Moore*). Fifteen examples, Munger.
—— bifurcatus, *Moore.* Two examples, Camerton.

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* The Camerton list is by Mr. C. Moore.

Turbo bullatus, *Moore.* Abundant at Camerton. Forty examples, Munger, Clan Down, and Radstock.

Pitonillus conicus, *D'Orb.* (P. turbinatus, *Moore*). Seventeen examples, Munger; Camerton, Tyning, near Timsbury, Clan Down. R.

—— linctus, *Moore.* Possibly a variety of the foregoing. Four examples, Camerton.

Phasianella turbinata, *Stoliczka.* (Trochus latilabrus, *Moore*). Forty-six examples, Munger, Clan Down. R.

Trochus acutus, *Schloth.* One example, Munger. G.

—— mammillaris, *Moore.* One example, Munger; one example, Camerton. R.

—— Thetis, *Goldfuss.* Nine examples, Munger. C. A. Y. R.

—— Ægion, *D'Orb.* (T. torosus, *Moore*), Camerton.

—— læviusculus, *Stoliczka,* Camerton.

—— Emylius, *D'Orb.* (T. granuliferus, *Moore*), Camerton.

—— limbatus, *Schloth.* (=T. Schubleri). Camerton. Twenty-four examples, Munger, Clan Down, and Radstock. G. R.

Eucyclus Guadryanus, *D'Orb.* (Trochus). (Trochus concinnus, *Moore*). Thirteen examples, Munger; two examples, Camerton. C. A. H. Y. D. R. G.

Eucyclus? politus, *Moore* (Turbo). One example, Camerton.

Chemnitzia undulata, *Zieten.* Sixteen examples, Munger. Y. C. G. R.

—— Blainvillei, *Goldfuss* (Scalaria liassica, *Quenst., Moore*). Seven examples, Clan Down and Munger; Camerton. Y. C. H. W. R. F.

—— anomala, *Moore* (Turritella). One example, Camerton.

Cerithium, sp. One example, Huish (*E. B. Tawney*).

—— camertonensis, *Moore.* One example, Camerton. C. A. F.

Actæonina Whitfieldii, *Moore.* One example, Clan Down.

—— marginata, *Simpson.* Two examples, Munger. Y. C. A.

Ostrea (G.) cymbium, *Lamk.*, and var. obliquata, *Sow.* Common in all the localities. Y. C. A. H. F.

—— semiplicata, *Münster.* Several examples, Munger and Radstock. G.

—— Goldfussi, *Bronn* (Gryphæa depressa, *Moore,* non *Phillips*; O. læviuscula, *Goldfuss,* non *Sow.*). Camerton, Bath Museum! Y. H.

Pecten lunularis, *Römer* (P. cingulatus, *Cat. Geol. Surv.* and *C. Moore*). Common at Munger and Radstock; Camerton, Boxton Hill (Geol. Surv.), Tyning. Y. G.

—— priscus, *Schloth.* Three examples, Munger; Tyning. Y. C. G. A. F.

—— textorius, *Schloth.* One example, Huish (*E. B. Tawney*).

—— substriatus, *Römer.* Two examples, Munger. Y.

Hinnites tumidus, *Zieten* (? Lima antiquata, *Moore*). Common at Munger and Radstock; ? Camerton, Tyning. Y. C.

Lima Hermanni, *Zieten.* Three examples, Munger. Y. C.

—— hettangiensis, *Terquem.* Four examples, Munger. F.

—— scabricula, *Tate.* One example, Munger. A. F.

—— eucharis, *D'Orb.* (L. punctata, *Moore*). One example, Radstock; a few examples, Munger; Tyning, near Timsbury; Camerton. Y. H. G. F.

Limea acuticosta, *Goldfuss.* Eighteen examples, Munger. Y. C. A. H. G.

Plicatula spinosa, *Sow.* Four examples, Munger, Camerton. Y. C. H. H. G. F. R.

—— sarcinula, *Goldfuss.* One example, Radstock, Camerton.

Avicula longiaxis, *Buckman.* Two examples, Munger. C.

Monotis inæquivalvis, *Sow.* Camerton. Y. C. A. H. G. H. F.

Inoceramus ventricosus, *Sow.* (? I. dubius, *Moore*). Common at Munger, Radstock, Camerton. Y. C. A. H. G. R. F.

Pinna folium, *Young and Bird* (P. fissa, *Geol. Surv. Cat.*). Common at Munger. Y. C. A. H. G.

Macrodon Buckmani, *Buckman* (Arca elongata, *Quenst.*) Four examples, Munger; Camerton. C. G.

—— intermedium, *Simpson.* Nine examples, Munger. Y. C.

Nucula cordata, *Goldfuss.* Four examples, Munger, Clan Down. Y. C. A. G.

Leda galathea, *D'Orb.* One example, Munger. Y. C. A. G.

Cardita consimilis, n. sp. (see p. 507). Six examples, Munger.

Opis clathrata, *Stoliczka.* Camerton.

Astarte striato-sulcata, *Goldfuss*. (A. Oppelii, *Moore*, non *Andler*). Eight examples, Munger; one example, Camerton. Y. C. A. H. G.

—— camertonensis, *Moore*. Common at Radstock and Munger; one example, Camerton, C. F.

Myoconcha decorata, *Goldfuss*. One example, Munger (Bristol Mus.). G. F. C.

Cypricardia cucullata, *Goldfuss*. One exemple, Munger. Y. G.

Cardinia attenuata, *Stutchbury*. One example, Munger, Y. C. H. F.

—— crassissima, *Sow*. One example, near Paulton (Geol. Surv.).

—— concinna, *Sow*. (?) Casts only, Munger (*R. T.*), and Huish (*E. B. Tawney*).

—— rugulosa. n. sp. (see p. 507). Three examples, Munger.

Ceromya bombax, *Quenst*. (Venus). Two examples, Munger. A.

Pholadomya ambigua, *Sow*. passim. H. C. G. F.

Pleuromya ovata, *Röm*. Many examples, Munger and Radstock. Y. G.

Waldheimia cornuta, *Sow*. Three examples, Radstock, Tyning. G.

—— indentata, *Sow*. Common at Radstock, Munger. G.

—— numismalis, *Lamk*. Common at Radstock, Munger, Clan Down, Tyning; Camerton. C. A. F. H. G. W. R.

—— quadrifida. One example, Boxton Hill (Geol. Surv.).

—— Waterhousei, *Davidson*. Common at Radstock, Munger; Camerton. A. R. G.

Terebratula punctata, *Sow*. Common at Radstock, Munger; Camerton. G. C.

—— Edwardsi, *Davidson*. One example, Munger (Bristol Mus.).

—— subovoides, *Röm*. (?). Not rare, Munger and Radstock. Y. F. G.

Spiriferina rostrata, *Schloth*. Four examples, Munger; eleven examples, Boxton Hill (Geol. Surv.). Camerton (*C. M.*), Huish (*E. B. Tawney*), Tyning. G. R. C. A. F.

Rhynchonella furcillata, *Von Buch*. Not common, chiefly in the highest bed, Munger, Radstock. G. F. W. C. F.

—— subconcinna, *Davidson*. One example, Munger (Bristol Mus.).

—— rimosa, *Von Buch*. Common at Munger, Radstock; Camerton, Clan Down. Y. G. R. W. F.

—— plicatissima, *Quenst*. A few examples at Radstock. Y. R. G.

—— (*cf.*) tetrahedra, *Sow*. One example, Huish (*E. B. Tawney*).

—— variabilis, *Schloth*. Abundant, Munger, Clan Down, and Radstock; Tyning; Camerton. C. A. Y. G. R. F.

Thecidea Bouchardi, *Davidson*. }
Leptæna Bouchardi, *Davidson*. } Munger (*C. Moore*).
—— rostrata, *Davidson*. }

Cricopora, sp. Clan Down.

Ditrypa capitata, *Phillips* (Serpula). A few examples, Munger, Radstock.

—— quinquesulcata, *Goldfuss* (Serpula). Three examples, Munger.

—— etalense, *Piette* (Ancyloceras). (Ancyloceras, sp., *Geol. Surv.*; Serpula strangulata, *Moore*). Common, Munger, Clan Down, Radstock; Camerton. R. A.

Serpula triangulata, *Sow*. Several examples, Munger, Radstock. C. W.

Galeolaria socialis, *Goldfuss*. Camerton.

Cidaris Edwardsii, *Wright*. Camerton.

Tropidaster pectinatus, *Forbes*. Munger (*C. Moore*).

Pentacrinus scalaris, *Goldfuss* ? Common.

Montlivaltia mucronata, *Duncan*. One example, Clan Down. F.

Description of New Species.

Trochus solitarius, spec. nov. Fig. 2.

Shell a little longer than broad, conical, imperforate; whorls 6–7, subconvex, separated by a well-defined suture, ornamented by oblique costæ (about thirty on the penultimate whorl) last whorl angular, a subtuberculated band at the suture, from which proceed oblique threads which serrate the keel, and radiate over the base; base convex, ornamented with about seven broad concentric ribs, and radially striated. Height ·3 inch; breadth ·2 inch.

One example, in a derived nodule. Conglomerate bed, Munger.

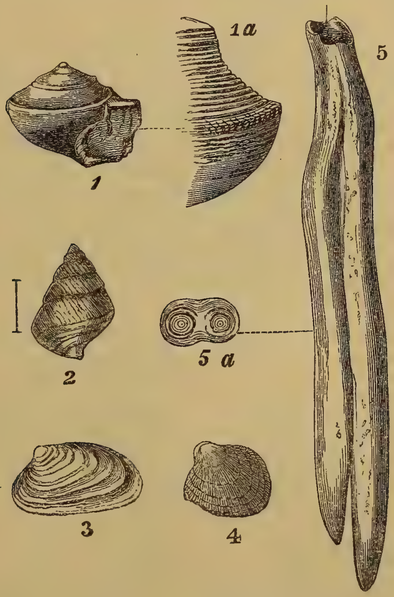
Cryptænia affinis, spec. nov. Figs. 1, 1*a*.

Shell shining, subdepressed, imperforate; whorls subconcave, ornamented with slender longitudinal ribs (about twenty), last whorl bluntly keeled; base convex, with a few longitudinal threads below the keel, the rest covered with fine concentric striæ; callus small and circumscribed. The sutural band is narrow, longitudinally ribbed, and marginal.

Allied to *C. expansa*, but has a different ornamentation and is more conical. Height ·6 inch; diameter ·7 inch.

Zone of *Am. Jamesoni*, S. of Paulton. Two examples (Geol. Surv.).

Figs. 1–5.—*Mollusca from the Lias about Radstock.*



1. *Cryptænia affinis*; 1 *a*. Portion of body-whorl enlarged. 2. *Trochus solitarius*. The line shows the natural size. 3. *Cardinia rugulosa*. 4. *Cardita consimilis*. 5. Belemnite, monstrosity. 5 *a*. Section of the same.

Cardita consimilis, spec. nov. Fig. 4.

Shell ovately tetragonal, transverse, compressed, umbones small, anterior, incurved; surface ornamented with radial costæ (more than sixty), and a few imbricating folds of growth.

Of the many scores of specimens of *C. multicostata*, Phillips (*Car-*

dium) which have passed through my hands, not one makes an approach to the form of this species. Length ·4 inch; height ·35 inch; thickness ·25 inch.

Zone of *Am. Jamesoni*, Munger. Six examples.

CARDINIA RUGULOSA, spec. nov. Fig. 3.

Ovate, transverse, compressed; umbones contiguous, small, incurved and anterior; lunule small, shallow, and cordate; escutcheon lanceolate, deep; hinge-line slightly arched, anterior side rounded, front straight, posterior side obliquely truncated; surface ornamented with thick folds of growth, the umbonal ones with erect lamellose edges. Length ·6 inch; height ·4 inch; thickness ·25 inch.

I know no adult shell with which this can be associated; if it be an immature form, it is then separable from *C. attenuata*, Stutchbury, *C. Listeri*, var. *hybrida*, Sow., and *C. antiqua*, Phillips, with the young shells of which I have compared it.

Zone of *Am. Jamesoni*, Munger. Three examples.

APPENDIX.

List of Species from the Yellow Lias, Hewlett's Hill, Cheltenham.

In my paper on the *A.-Jamesoni* beds of Cheltenham, no notice was taken of the fossils from the "Yellow Lias," placed by Oppel on the horizon of *Ammonites ibex*. Researches made in other districts induced me to suppress this zone, though the prevailing Ammonites are very restricted, as the majority of the species are those of the *A.-Jamesoni* series. A list of the species may be serviceable for comparison; the prefixed sign (!) indicates that specimens have been examined by me:—

Ammonites centaurus, *D'Orb.* fide *Oppel.*
! —— Henleyi, *Sow.*
! —— fimbriatus, *Sow.*
—— ibex, *Quenst.*
—— Loscombi, *Sow.*
—— Maugenesti, *D'Orb.*
—— Valdani, *D'Orb.* } fide *Oppel.*
! Belemnites umbilicatus, *Blainv.*
! —— clavatus, *Schloth.*
! Pleurotomaria similis, *Sow.*
! Eucyclus imbricatus, *Sow.*
! Chemnitzia undulata, *Ziet.* (*Brodie*).
! Trochus acutus, *Schloth.* v. 2.
! Turbo admirandus, *Tate.*
! Solarium inornatum, *Tate* (*Brodie*).
! Dentalium angulatum, *Buckman.*
! Actæonina marginata, *Simpson.*
! Pecten priscus, *Schloth.*
! Hinnites tumidus, *Ziet.*
! Lima Hermanni, *Ziet.*
! Limea acuticosta, *Goldfuss.*
! Avicula longiaxis, *Buckman.*
! Gervillia lævis, *Buckman.*
! Inoceramus ventricosus, *Sow.*
Modiola scalprum, *Sow.* (*Oppel*).
! Macrodon Buckmani, *Buckman.*
! —— intermedium, *Simpson.*
Arca Stricklandi, *Tate* (*Buckman*).
! Leda galathea, *D'Orb.*
! —— minor, *Simpson.*
! Cypricardia cucullata, *Goldfuss.*
! Hippopodium ponderosum, *Sow.*
! Cardium truncatum, *Sow.*
! Cardinia attenuata, *Stutch.*
! Arcomya elongata, *Röm.*
! Pholadomya ambigua, *Sow.*
! Pleuromya ovata, *Röm.*
! Terebratula punctata, *Sow.*
! Rhynchonella furcillata, *Buckman.*
! —— subconcinna, *Davids.*
! Spiriferina rostrata, *Schloth.* (*Buckm.*).
! Ditrypa quinquesulcata, *Goldfuss.*
! Pentacrinus moniliferus, *Quenst.*
—— robustus, *Wright*
Acroura Brodiei, *Wright*
Ophioderma Gaveyi, *Wr.* } fide *Wright.*

Section, Railway-cutting, Fenny Compton, Warwickshire, eight miles north from Banbury.

This section is the only one of any extent in the basal beds of the Middle Lias, excepting those on the Dorset and Cleveland coasts; and though it presents no junction with the Lower Lias, yet it exhibits that palæontological uniformity which is insisted upon for this horizon throughout the British area. From it, in conjunction with that of Radstock, we also learn that the prevailing species of the zone are unaffected by the nature of the rock. The measures are those made by T. Beesley, Esq., F.C.S., in whose company I have examined the section, and noted the positions of the fossils recorded.

		ft.	in.
1.	Lias clay disturbed	6	0
2.	Shaly clay, with a band of ferro-claystone nodules about 5 ft. from base, containing *Ammonites ibex*, *A. Valdani*, *A. Maugenesti*, *A. Henleyi*	30	0
3.	Blue, weathering grey, argillaceous limestone, *A. Valdani*, *Bel. clavatus*, *Pholadomya decorata*, *Gryphæa obliquata*, *Inoceramus ventricosus*, *Lima hettangiensis*, *Waldheimia numismalis*, *Spiriferina verrucosa*, *Rhynchonella rimosa*	1	0
4.	Shale	4	0
5.	Friable argillaceous limestone, *A. Loscombi*, *A. Jamesoni*, *Belemnites*, *Modiola scalprum*, *Limea acuticosta*, *Plicatula spinosa*, *Cardinia attenuata*, *Pecten priscus*, *Waldheimia numismalis*, *Rhynchonella rimosa*, *R. variabilis*, Corals	0	9
6.	Shale	2	0
7.	Band of nodules, *Unicardium cardioides*, *Pecten priscus*, *P. calvus*, *Limea acuticosta*, *Terebratula subovoides*	0	2
8.	*Gryphæa*-band—occasionally a yellow stony bed. *Bel. clavatus*, large *Gryphæa obliquata*	1	0
9.	Limestone nodules	0	2
10.	Shale	5	6
11.	Argillaceous limestone nodules, *Pecten calvus*, *Terebratula subovoides*?	0	3
12.	Clay with small claystone nodules, fossils throughout, but chiefly in the lower 30 feet. *Ammonites armatus*, *Bel. breviformis*, *Cerithium Slatteri*, *C. camertonensis*, *Dentalium angulatum*, *Pecten priscus*, *Plicatula spinosa*, *Gryphæa obliquata*, *Leda minor*, *Waldheimia numismalis*, *Rhynchonella variabilis*, Crustaceans	80	0
	Total	130	10

The total number of species, collected from this section, which embraces the subzones of *A. Henleyi*, *A. Jamesoni*, and *A. armatus*, is 109, one of which is undescribed; I will call it PROTOCARDIUM BOMBAX. This new species is distinguished from its Liassic congeners by its globose form, inflated beaks, and by the numerous (50) fine, serrated, radial striæ on the narrow, subconcave, posterior area; dimensions, height 1·1 inch, breadth 1·05 inch, thickness 1 inch.

DISCUSSION.

Prof. DUNCAN remarked that in the lateral extension of the Ammonite-zones the forms are modified, and that species regarded in one area as on different horizons, may be brought together in the same zone in another district. He was glad to hear of the occurrence of *Ammonites angulatus* at Radstock, as that species characterizes a very remarkable zone in Luxembourg and elsewhere on the continent.

Prof. RAMSAY said that the Lower Lias consists of a regular succession of deposits without unconformity, reaching with us a thickness of some 900 feet. He stated that lithologically there is no line of demarcation between the Lower Lias and the Marlstone, and that, from a palæontological point of view, the two series cannot be divided, as many of the species are common to both. If there were any great divisions at all, they were between the Upper and Lower Lias, and between the latter and the Oolite; but the whole Lias and Oolite really constitute one great formation, in which, from the sands of the Inferior Oolite to the Lower Lias, the divisions are not constant, and only apply to limited areas. Much of the fauna was local.

Rev. J. F. BLAKE remarked that Oppel, who was a man of great and extended experience, established zones and believed in them. He thought that zones might be recognized as continuous in the Lias all over England, in Gloucestershire, at Lyme Regis, and in Yorkshire. He said that there was undoubtedly a great break between the Lower and Middle Lias, when the line was drawn palæontologically; and in the upper part of the Lower Lias the species diminish in number, and with the Middle Lias new forms are introduced. There is also a break between the Upper and Middle Lias.

Mr. HICKS thought that these might be variations in the forms in different localities.

Prof. RAMSAY said that if lines of demarcation were drawn palæontologically and not lithologically, they might be drawn across several formations that were really contemporaneous.

Mr. CHARLESWORTH doubted whether species could be defined, and instanced cases of divergent opinions on the part of different naturalists as to the determination of species of Mollusca.

Mr. KOCH inquired whether there might not be colonies of Ammonites as well as of Trilobites, in accordance with Barrande's theory.

38. *Some* Observations *on the* Rev. O. Fisher's Remarks *on* Mr. Mallet's Theory *of* Volcanic Energy. By R. Mallet, Esq., F.R.S., F.G.S. (Read June 23, 1875.)

Mr. E. W. Hilgard, Professor of Geology in the University of Michigan, in a paper "On some points in Mallet's Theory of Vulcanicity" (Amer. Journ. Sci. vol. vii. June, 1874), has remarked that that author's experiments ("On the Nature and Origin of Volcanic Heat and Energy," Phil. Trans. 1873) "fail to carry conviction as to the efficacy of this particular *modus operandi* in reducing large masses of solid rock to fusion—unless essentially supplemented by *friction*, and the heat produced within more or less comminuted, detrital, or igneo-plastic masses by violent pressure and deformation."

The author's crushing-experiments had not for their object to prove how high a temperature could be by this process and its consequences attained in nature; and he has in his paper above referred to entered into no details on this point of the subject; to have done so would have too largely extended an already long paper. Moreover he considered that every physicist interested in the subject would follow out for himself the conditions and consequences of the work of crushing in our globe's crust, and discern that there was no physical impossibility in a temperature of rock-fusion resulting therefrom. The object of the author's experiments was to fix what was the annual minimum amount of heat available for vulcanicity in our entire globe upon the mechanism which he has assigned. For this purpose the crushing of cubes of rock in air was alone available: his experiments prove what total minimum amount of heat must be so produced, but do not, and never were intended to prove what maximum amount of temperature may be locally attained as a consequence of the circumstances following crushing as it occurs in nature and deep beneath the surface; and Professor Hilgard remarks that the burden is thrown upon the opponents of the author's theory to prove "the *qualitative* inefficiency of the several modes of action that may come into play."

The views expressed by Professor Hilgard anticipate those of the Rev. O. Fisher brought before this Society, Professor Hilgard merely pointing out that there is an absence of proof of experimental rock-fusion in the author's paper, whereas the Rev. O. Fisher seems to think that the author's theory is, in the absence of this proof alone, to be wholly discredited. There are many things in Mr. Fisher's paper read to this Society which have so little direct relevancy to the author's views as to the nature and origin of volcanic heat, &c., that he may pass them by here with but slight notice. It is wholly immaterial to the author's views, for example, whether those of Sir W. Thomson and of General Barnard as to the rigidity of our globe as a whole be true or false; nor has it the slightest direct bearing upon the author's views whether that which he has expressed as a mere "opinion," namely, that the great oceanic and continental areas are on the whole very much unchanged since the period when our earth's crust was extremely thin, be correct or incorrect. The author believes that there is much to support this view, and that the geological circumstances adducible against it present no certain disproof of it; but he is not called upon here further to refer to it. Nor is it necessary that the author should dwell at any length upon the Rev. O. Fisher's assertion that in the estimate of the annual supply of heat consumed in supporting existing vulcanicity, Mr. Mallet has not allowed sufficiently for projection of lapilli and dust, nor for corrugation of the earth's crust at present supposed to be taking place, these objections, even if valid, having no direct relation to the Rev. O. Fisher's objection as to local temperature being insufficient for fusion. The author has *doubled* the units of heat to allow for waste; and in this, ample allowance is made for dust &c. projected above volcanic summits. In his view there is little or no corrugation now going on, the existing thick crust only admitting of crushing; and even if there were, as the annual demand to supply existing vulcanicity is less than $\frac{1}{1589}$ of the total heat annually dissipated from our globe, we have an ample magazine to draw upon for this supposed corrugation, if any such existed (Phil. Trans. 1873, §§ 179–197). The pith of the Rev. O. Fisher's objections is comprised in the two following extracts in his own words:—

"Indeed the form in which the objection to Mr. Mallet's reasoning suggested itself to my mind on first reading his paper was simply this. If crushing the rocks can induce fusion, then the cubes experimented upon ought to have been fused in the crushing. And I still adhere to this simple mode of expressing my objection." Again, "he considers that the heat so developed may be localized, and that the heat developed by crushing, say ten cubic miles of rock, may fuse one cubic mile; but, I ask, why so? the work is equally distributed throughout. Why should not the heat be so also? or if not, what determines the localization? For example, suppose a horizontal column ten miles in length and one in sectional area to be crushed by pressure applied at its ends, which of the ten cubic miles is to be the one fused? But if no cause can assign one rather than another, it is clear that they will all be heated by 170° F.*, and none of them fused."

If a cube of rock which in free air is found to crush under a certain pressure, be imagined situated deep within a mass of similar rock, and there crushed, it does not admit of dispute that the work necessary to effect crushing must be largely increased; the particles of the cube and of the entire mass of surrounding rock are under the insistent pressure of the superincumbent rock in a state of elastic equilibrium. It follows therefore that the pressures of the surrounding rock produce the same effect upon the cube, as regards resistance to crushing, as if they were cohesive forces acting within

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* The mean deduced, apparently, by the Rev. O. Fisher from the last five or six experiments in the author's Table I.

the cube; and the work necessary to crush the cube by its finally giving way, in whatever direction this *encastrément* by pressure may be least, will be increased over that which would crush it in free air nearly in the same ratio in which the imaginary cube is exposed to external pressure greater than that in air—and this, neglecting the cohesive resistance of the surrounding rock itself.

Thus, if the cube of Guernsey granite, no. 12 in the author's Table No. 1, were crushed at a depth of twenty miles beneath like rock, it would have required to crush it a pressure of 4·28 times as much as was found necessary to crush it in air; and if we assume the displacement of the crushed particles after crushing to be the same as in the case of the cube crushed in air, then the work and the heat due to its transformation will also be 4·28 times as great; and as in the case of the cube crushed in air the heat developed was sufficient to fuse (at 2000° F.) 0·108 of its own volume, or in other words that the crushing of ten cubic feet of the rock would be required to raise to that point one cubic foot, so in the case of the imaginary cube situated at the depth of twenty miles, enough heat would be evolved by the work of crushing each cubic foot to fuse 0·462 cubic foot of the same rock, or nearly half the volume crushed—and this, assuming that the initial temperature of the rock at twenty miles depth was only 53° F., as in the author's experiments, instead of from 500° to 1000° or more, as it may be at twenty miles depth. Therefore, under the pressure due to a depth of twenty miles and an initial temperature of 1000° F., the heat developed by the work of crushing each cubic foot of rock will be sufficient to fuse its own volume. Thus also if we assume the fusing-point of the rocks not to be 2000° F., as indicated by the author's experiments on the cooling of slags, but considerably higher, say 2500° or more, we have still a sufficient supply of heat to bring 0·8 of the whole to fusion. These considerations, apart from all others yet to be adverted to, appear fully sufficient to refute the Rev. O. Fisher's first objection above quoted. Indeed the statement that if under any circumstances and in the rock-masses of nature "crushing can induce fusion, then the cubes experimented upon ought to have been fused in the crushing" wholly ignores the differences of condition in the two cases, and seems as unsustainable as it would be to affirm that no heat is developed by the slow oxidation (eremacausis) into water and carbonic acid of a pound of wood, which, when burned, develops a well-known amount of heat.

The writer now proceeds to reply to the second objection of the Rev. O. Fisher as above quoted, which appears to him based entirely on a misconception of the physical conditions involved. Let us consider what will happen in the case of a prism or column of rock crushed against the face of an unyielding mass. If the prismatic mass be not homogeneous throughout, crushing will commence at the weakest place; if it be perfectly homogeneous, crushing will commence and continue where the prism is in contact with a fixed mass, and that whether the prism be crushed at one or both ends, because it is at such surfaces of contact that the *compression* of the particles of the prism is greatest, and where therefore the elastic limit of their cohesion is first and successively overpassed. This may be seen illustrated in the stonework of buildings the material of which is overloaded, and where crushing or spalling off of the ashlar stones only occurs at and near the joints. In either case, whether the prism be homogeneous or not, the crushing must be localized either to the end or ends of the prism or to the plane of weakness where it first yields, and which then becomes the crushing-surfaces of the two opposed prisms. It is these physical conditions which "determine the localization" of crushing in the prism; and these conditions have been disregarded in the Rev. O. Fisher's objection.

Having already shown that crushing alone under natural conditions may suffice for fusion, and, secondly, that the heat produced by crushing under natural conditions *must* be localized, the author now proceeds to show that by successive crushing successive augmentations of temperature must result. Let us consider the effects of the successive crushing of a column or prismatic mass of rock one extremity of which is continually urged against the face of a fixed mass of rock which does not yield—a case which approximates to that which most frequently occurs in nature, and which, to fix our ideas, we may suppose presents a face for crushing of one square foot; and being continually urged forward, the compression being greatest where the pressing column comes into contact with the fixed mass of rock, the extremity of the column, supposed homogeneous, or the parts adjacent thereto, are continually crushed by a succession of *per saltum* movements.

The first cubic foot of the column that is crushed has its temperature raised, let us suppose by 217° F.; the crushed fragments at this temperature are pushed aside by the advancing column, whose extremity is thus surrounded by the crushed material at a temperature of 217° plus the initial temperature, and the second foot in length of the column becomes crushed; but the material of this second cubic foot is at a higher temperature before it is crushed than was the first cubic foot, so that the heat due to the transformed work of crushing of each successive cubic foot of rock raises its temperature to a higher point than that of the preceding one, because each successive cubic foot at the instant before crushing is at a temperature already higher than the preceding ones, resulting from the heat taken up by the uncrushed column from the hotter portions of material surrounding it that has already been heated by crushing; so that if T be the temperature produced in the first cubic foot crushed, and t be the temperature of the crushed material which communicates a portion of its heat to the next cubic foot crushed, the temperatures of the successive cubic feet crushed may be illustrated by some such series as the following:—

Cubic feet crushed.

No. 1.	No. 2.	No. 3.	
T	$T+\frac{t}{n}$	$T+\frac{t}{n}+\frac{t}{m}$.	. . . .

n and m being the denominators of the fractions of the heat in the débris successively transmitted to the second and third cubic feet of the uncrushed part of the column.

No limit arises to this continual augmentation of temperature while the rock retains its rigidity; after that has been seriously impaired or lost, any further exaltation of temperature becomes dependent upon the deformation and detrusion of a more or less plastic mass. It is well ascertained, however, by observation on a great scale, that granite remains rigid at a temperature approaching that of the softening-point of cast iron, so that a large range of rigidity must exist for the exaltation of its temperature in the way above suggested; and in the state of aggregation in which we are warranted in supposing rocky masses to exist at considerable depths, it is probable that this range of rigidity would be even further extended than in the case of granite found at or near the present surface of our globe. Fire-brick also retains its rigidity far above bright redness and to within a short range of its melting-point.

Besides the heat transformed from the work of compression and crushing, a large amount of heat must also be generally produced by transformation of the work expended in friction and detrusion. No experiments have as yet, to the author's knowledge, been made upon the amount of heat developable in pulverulent masses such as sand and fragments of various sizes, by the forcible transposition of more or less of the particles; nor do we know with certainty the conditions under which external mechanical pressure is transmitted through like discontinuous matter. As in rigid solids exposed to unequal mechanical pressures there exist planes or surfaces within the mass such as, in solids, have been denominated by Moseley "planes of easiest shearing," so in masses of fragmentary matter, whatever be the shape or size of the particles, provided these be small in relation to the whole mass, and their mutual adhesion, if any, small also, such shearing-planes must by unequal mechanical pressure be brought into existence. Along any such plane we may imagine the sand or other pulverulent matter forced to move over itself in opposite directions at opposite sides of the plane; that is to say, we may suppose the sand forced along such a plane much in the same manner that a mass of sandstone or of granite would be forced along such a shearing-plane as had been produced in it previously by mechanical pressure. If this reasoning be admitted, we must suppose that heat would be developed along such a plane and at short distances from it in a way more or less analogous to that produced by the forcing of one rough surface of stone over another. What the coefficient of friction in this case would be, can only be determined by experiment; but we may justifiably conclude that the amount of friction per unit of surface would increase proportionately to the pressure applied externally to the entire mass, and exposed to more or less of which, motion at any such surface of friction must take place. Coulomb, Morin, and others have found the friction of some sorts of rough stone upon other rough stone to reach as much as three fourths the pressure; and should this coefficient increase proportionately under the enormous pressures to which a discontinuous mass at several miles depth may be subjected, we can readily see that the transformed heat of friction produced by internal movements taking place in such materials after crushing has occurred, must be the source of a large amount of heat over and above that originally due to the crushing itself. Thus, for example, if we assume a surface of one square foot of such disintegrated material sliding over a similar surface, or over a rough surface of coherent rock, and under the pressure of ten miles of rock of the specific gravity of granite, at the rate of one foot per second, and we take the coefficient of friction as low as 0·5, we have 4,326,600 foot pounds of frictional work per second, which, divided by J (772), gives 5604 units of heat evolved per second from each square foot of surface; and to this development there is no limit while the circumstances continue the same and the motion is continued; and great as is this evolution of heat under such enormous pressures, it would be further increased in the event of the fragmentary particles being heated so as to present incipient viscosity of surface and more or less of mutual agglutination.

Temperature, in respect of any given solid material, is dependent upon the units of heat present in a unit of mass or of volume of the substance. If for the same total heat we diminish the mass or volume, the temperature is proportionately increased. When the material is surrounded by matter capable of carrying off heat by conduction, or evection, or radiation, and the heat is evolved within the mass by work done upon it, then another condition, that of time, has to be taken into account; for the shorter the time within which a given amount of heat due to transformation of work is evolved within the unit of mass, the less of that total is dissipated by conduction &c.

In the case of the $1\frac{1}{2}$-inch cubes in the author's experiments, the work of crushing could not take place more rapidly than a heavy body could fall freely through a space of rather less than 1·5 inch. In nature, however, the opposed rock-surfaces are brought into a state of elastic compression, the release of which by crushing takes place with a velocity proportional to the elastic modulus of the rock, probably not less than 10,000 feet per second. Had the rock specimen crushed in the author's experiments been a cubic foot in place of an inch-and-half cube, the time of crushing due to gravity must have been rather more than ·249 second, or nearly a velocity of 2 feet per second, which is less than $\frac{1}{5000}$ of the velocity with which the same might have been crushed if circumstanced as in the shell of our globe. And if we extend our view from the crushing of a cubic foot or two to that of a cubic mile or more, we see that there would be very little of the total heat evolved lost by dissipation, there being scarcely any time in which that could occur.

Another and further source of heat arises after crushing and detrusion of the fragmentary matter, and after the latter has arrived at a temperature at which the fragments have become more or less viscous and adherent by reason of the further work expended in the deformation and detrusion by forcing forward, through highly irregular or constricted rock-channels, the now heated and viscous mass.

There do not exist at present sufficient data by which to calculate the amount of work necessary to a given amount of deformation in viscous masses; and hence we cannot calculate the amount of heat that in nature might arise from it. Hirn, however, has shown that, in the case of plastic bodies such as lead, the heat developed is proportional to the work done in deformation; so that if we knew the pressure per unit of surface necessary to produce a certain deformation in an already heated mass of given viscosity, we could calculate how much its temperature would be exalted by the work of the assigned deformation.

The action of the machine employed in the arsenal at Woolwich for making lead rods to be afterwards pressed into bullets affords a striking example. In this machine a cylindrical block of lead maintained at a temperature of 400° F., is by a steady pressure upon the end, which is 8·5″ in diameter, of 16,700 lb. per square inch of its surface, forced through an aperture at the other extremity into a rod of 0·525 inch diameter, at such a rate that 5 inches in length of the cylindrical block becomes a rod about 100 feet in length, of the above diameter, per minute. We have thus 393,906 foot pounds of work done upon the lead per minute, dividing which by J we have 510·2 British units of heat developed per minute from the transformed work. In the actual machine the whole of this is ultimately dissipated and lost; but if none of it were dissipated, as the cylindrical block of lead of 8·5″ diam. by 0·416 foot in length weighs 116·3 lb., and the specific heat of lead is =0·029 (or perhaps a little more at 400° F.), it follows that the heat developed by its deformation from the short cylindrical block of 5 inches length to a rod of about 100 feet is enough to raise the temperature of the lead through 151° F., or, were no heat lost, to raise its temperature from 400° to 551° F., or thereabouts—that is, to within about 50° of its melting-point. If, therefore, the velocity of deformation were greater by one fourth, the lead would be melted, assuming the latent heat of liquefaction to be small. Or if we could by a reverse process squeeze the 100-feet rod back into the original block of 8·5″ × 5″, we should find the lead in the latter not only liquid but considerably above its temperature of fusion. It is obvious therefore that any viscous or plastic body, such as lava, continually forced through apertures varying in area and form and suffering continual deformation, as when forced through a volcanic tube or vent, must have its temperature continually exalted so long as it continues thus to be urged forcibly forward, assuming, as is very nearly the truth in nature, that an extremely small proportion of the heat developed in the process can be dissipated by conduction to the walls of the tube.

The writer has thus shown that crushing alone of rocky masses beneath our earth's crust may be sufficient to produce fusion. He has also shown that the heat developed by crushing alone cannot be equally diffused throughout the mass crushed, but must be localized, and that the circumstances of this localization must result in producing a local temperature far greater than that due to crushing.

Lastly he has shown that, after the highest temperatures have been thus reached, a still further and great exaltation of temperature must arise from detrusive friction and the movements of forcible deformation of the already crushed and heated material.

It appears to the writer, therefore, that he has sufficiently shown that there is no physical difficulty in the conception involved in his original memoir (Phil. Trans. 1873), but not there enlarged upon in detail, that the temperatures consequent upon crushing the materials of our earth's crust are sufficient locally to bring these into fusion.

Discussion.

Prof. Duncan remarked that this reply to Mr. Fisher's paper, which is not yet in print, was one which required careful thought and consideration. He thought that Mr. Mallet had not considered sufficiently the effects of tangential thrust. The curving of strata takes place along great planes, producing main synclinal curves; but there was another series of actions giving rise to thrusts over smaller areas. In any case the action of the thrust would be slow, and thus it can furnish no parallel to experiments by crushing rocks, in which the effect was rapidly produced. He further pointed out that volcanoes do not follow mountain-chains, and that the crust of the earth has no doubt become more rigid than formerly, and that therefore tangential thrusts would now be less effective. Volcanic cones are found in older rocks than the Eocene.

Prof. Ramsay said that he agreed with Prof. Duncan in general, but thought that the meaning of quick and slow was difficult to define in connection with great thicknesses of strata. If the pressure was sufficient to maintain motion, this might be quick in one sense and slow in another. Alterations may be gradually going on over great areas, by which means metamorphism may be evidenced in different degrees in different parts.

The President remarked that, assuming gravity to be free to act, the pressure at a depth of 20 miles would be about 120,000 lb. to the square inch, and that but little was known as to the behaviour of granite under such a pressure.

39. *On the* AGE *and* CORRELATIONS *of the* PLANT-BEARING SERIES *of* INDIA, *and the former* EXISTENCE *of an* INDO-OCEANIC CONTINENT. By HENRY F. BLANFORD, Esq., F.G.S. (Read December 16, 1874.)

[PLATE XXV.]

THE Peninsula of India (by which term I denote the whole of the country lying to the south of the Indo-Gangetic plain) has but little in common, in point of geological structure, with the ranges that encircle that plain on the north, or, indeed, with any of the neighbouring countries beyond, as far as these are known. The marine fossiliferous formations of Palæozoic age which are known to be largely developed in the Himálaya and the Salt range of the Punjáb, have no assignable representatives to the south of the Ganges; and the Neozoic marine formations of the same mountains, of the western ranges, and those of Eastern Bengal are represented in the Peninsula only by the Jurassic and Tertiary rocks of Cutch, the small Cretaceous formation of Trichinopoly, the somewhat older deposits of Bagh, &c. on the Lower Nerbudda, and the Nummulitic conglomerates of Broach and Surat. With these exceptions and the probably estuarine deposit of Rajamundry (of the date of the Deccan traps), and some recent coast-formations, the peninsula is formed exclusively of crystalline (chiefly metamorphic) rocks of high antiquity, of volcanic rocks, and great sedimentary formations, which are either unfossiliferous, or which contain the remains of plants and animals such as, with rare exceptions, indicate a freshwater origin and the immediate proximity of land.

The oldest of these, termed by the Geological Survey the Vindhyan and Infra-Vindhyan formations, have hitherto proved quite unfossiliferous; and their age is consequently unknown. But overlying these (very unconformably), and occupying much of Central India and the north-eastern part of the peninsular region, come the formations sometimes designated as the great Plant-bearing Series, the age of which and of their fossil contents has frequently been discussed in the pages of the Society's Journal and elsewhere. The latest general and comprehensive discussion of this subject is that given by Dr. Oldham in the second and third volumes of the 'Memoirs of the Geological Survey of India;' but later notices of parts of the series have appeared in the 'Memoirs and Records of the Geological Survey;' and several excellent papers on the geology of other countries have been published, chiefly in the Society's Journal, which help to throw light on the correlations of the Indian rocks. Having lately had occasion to investigate this question, with the help of this later evidence, I venture to submit the results to the Society, and at the same time to put forward some speculations respecting the ancient physical geography of an adjoining region, which, though not entirely original, have not, I believe, as yet been published in a definite form.

The plant-bearing formations of India exhibit some diversity of character in different parts of the area; so that it will be convenient to notice them under their several geographical divisions, viz.:—I. Western Bengal; II. Orissa, Sirgúja, South Behar, and South Rewáh; III. the Sátpúra basin of Central India; IV. the Godavery basin; V. Trichinopoly and Madras; and VI. Cutch (see Map, Pl. XXV.).

I. The first division includes the coal-basins of the Dámúdá valley (all of which have been described and mapped in detail) the Rájmahál hills, and the numerous small basins, some less than a square mile in extent, which are dotted over the gneiss plateau to the west of the Gangetic delta. Of these basins (with the exception of the Rájmahál hills) the Ràniganj coal-field may be taken as the type. In it all the lower groups of the plant-bearing series of Bengal are characteristically developed and attain their greatest aggregate thickness. Of these Mr. W. T. Blanford has distinguished the following, enumerated in descending order*:—

1. Coarse sandstones and conglomerates		500 feet.
2. The Panchét group		1500 „
3. The Ràniganj group	Dámúdá series	5000 „
4. The Ironstone shales		1400 „
5. The Barákar group		2000 „
6. The Talchír group		800 „

making a total of 11,200 feet. In the Jherria field to the west†, the Barákar group has a thickness of 3000 feet; and in the Bokáro field, still further west‡, the topmost sandstone formation is 1500 feet, the Panchét group 1800 feet, and the iron shales 1500 feet; so that the total maximum thickness of all these deposits, as represented in the Dámúdá valley, is not less than 12,600 feet.

Plant-remains have been met with occasionally in all the subdivisions; but in many cases they are fragmentary and ill preserved. The fossil flora of the Ràniganj group is the best preserved, and, although never yet described and published in a complete form, is the best-known. Dr. Oldham gives the following numerical list of the species of the Dámúdá series§, including the recognizable plants of the Barákar group. I exclude one species of *Zamia*, given with a [?] in the list, since no plant of this genus has ever been met with by the Survey in these rocks, and its authenticity is very doubtful‖.

Sphenophyllum	3 species.	Pecopteris	4 species.
Vertebraria	2 „	Glossopteris	5 „ (?)
Phyllotheca	2 „	Calamites	1 „
Cyclopteris	1 „	Schizoneura	2 „

The fossils of the Barákar group differ from those of the Ràniganj

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* Mem. G. S. I. vol. iii. part 1, p. 31. Group 1 is designated as the Upper Panchét; but this name has since been abandoned. And for the name Lower Dámúdás (Group 5), the name given in the text has been universally substituted.

† Hughes, Mem. G. S. I. vol. v. Art. 4, p. 245.

‡ Hughes, Mem. G. S. I. vol. vi. Art. 3, pp. 3, 67, 59.

§ Mem. G. S. I. vol. ii. p. 326.

‖ See note to the list, *op. et loc. cit.*

group[*] in the absence of *Sphenophyllum* (*Trizygia* of Royle), and of a species of *Schizoneura* that is very abundant in the upper group and characteristic of it; while an allied form, which does not occur in the Ràniganj group, is found in the Barákars. Dr. Oldham also mentions that *Pecopteris*[†], *Sphenopteris*, and *Phyllotheca*[‡] are almost wanting in the latter, while they are well represented in the former. The most characteristic plants of the Ránigan group, besides the *Schizoneura* above mentioned, are *Glossopteris Browniana*, Brongn., *Phyllotheca indica*, Bunbury, and *Vertebraria indica*, Royle.

In the overlying Panchét group Dr. Oldham enumerates[§] six or eight species in all, viz.:—the genera *Schizoneura*, 1 species, apparently distinct from that of the Ránigan group; *Tæniopteris*, 1 species; *Sphenopteris*, 2 species; *Neuropteris* (?), 1 species; *Preissleria*, 1 species. In the upper part of the same group occur the Reptilian and Amphibian remains referred by Prof. Huxley[||] to two new genera of Labyrinthodonts, a Dicynodont, and a Thecodont saurian (*Ankistrodon indicus*, Huxley); also Entomostraca, the most abundant being an *Estheria*, doubtfully identified with *E. mangaliensis*, Jones, from Central India.

In the Rájmahál hills, the Talchír and Barákar groups are overlain by coarse sandstones (Dubrájpúr group[¶]), probably representative of those at the top of the Ránigan section (the Panchéts being wanting); and on these rest, very unconformably, rocks of a distinct group, the Rájmahál group, interbedded with contemporaneous trap-flows, and containing the flora figured and described by Dr. Oldham and Prof. Morris in the 'Palæontologia Indica'[**]. This flora, as is well known, is characterized by the abundance of its Cycads, and is quite distinct specifically, and for the most part generically, from that of any of the older groups. Two of them have been identified with plants from the Cutch deposits. The following generic list is given by Dr. Oldham[††]:—

Equisetum	2 species.	Walchia	1 species.
Cyclopteris	1 ,,	Cycadites	2 ,,
Dictyopteris	2 ,,	Pterophyllum	9 ,,
Pecopteris...	5 ,,	Palæozamia	8 ,,
Sphenopteris	3 ,,	Stangerites	2 ,,
Tæniopteris	3 ,,	Voltzia	1 ,,
Cardiocarpon	1 ,,	Brachyphyllum	1 ,,
Lycopodites	3 ,,		

with wood of *Dadoxylon*, *Palæoxylon*, *Taxoxylon*, Cycads, and Dicotyledonous Angiosperms of three or four varieties. No animal remains have been met with in the Rájmahál hills.

II. In Orissa, Sirgúja, South Behár, and South Rewáh, representatives of the Ironstone shales, Ránigan and Panchét groups are wanting. The Talchír and Barákar groups are overlain by coarse

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[*] W. T. Blanford, Mem. G. S. I. vol. iii. Art. 1, p. 43.

[†] *Op. cit.* vol. iii. p. 207.

[‡] Mr. W. T. Blanford, however, states (*loc. sup. cit.*) that *Phyllotheca* abounds throughout the Dámúdá series.

[§] *Op. cit.* vol. iii. p. 204.

[||] Pal. Ind. vol. iv. pt. 1.

[¶] Pal. Ind. ser. ii. pt. 1.

[**] Pal. Ind. ser. ii.

[††] Mem. G. S. I. vol. ii. p. 318.

sandstones, which in South Rewáh attain to a great thickness. The reports and maps of this field have not yet been published; but the rocks occurring in the Mahánadi valley, at its north-western extremity, have been briefly described in Mr. J. G. Medlicott's Report on the central portion of the Nerbudda district*. In this valley and that of the Johilla, two groups of rocks, in addition to those above noticed, appear, termed the Laméta and Jabalpúr† groups, only the lower of which is included in the plant-bearing series. It contains the remains of Cycads and Coniferous plants, some of which have been identified with those of the Rájmahál group. Dr. Oldham considers that it represents in the Nerbudda district the lower portion of the Rájmahál group‡.

III. In the Sátpúra field, lately described by Mr. H. B. Medlicott§, the plant-bearing series attains an enormous thickness. The Talchír and Barákar beds appear at the base; but the overlying groups are only doubtfully to be identified with those of Western Bengal. The following is their succession, in descending order, with their respective thicknesses, as given by Mr. Medlicott:—

1. Jabalpúr group		500 or 600 feet.
2. Bágra group	Mahádéva series	800 ,,
3. Denwa group		1200 ,,
4. Pachmari group		8000 ,,
5. Almód and Bijóri group		3000 to 4000 ,,
6. Motúr group		?
7. Barákar group		400 or 500 ,,
8. Talchír group		?

The maximum aggregate thickness of these beds is therefore upwards of 15,000 feet. Group 5 is considered by Mr. Medlicott to represent the Panchét and Ránigani groups of Bengal [and perhaps the Kámthis and Panchéts of the Godavery valley]. In the Bijóri, or lower part of this group, were found the remains of an *Archegosaurus* ||, the only fossil of animal origin hitherto met with in the whole of this enormous series. Imperfect plant-remains also occur in the same group.

IV. Passing to the Nagpore country and the Godavery valley, the character of the series again alters. The Talchír and Barákar groups are still constant at the base of the series; and on them rest a group of rocks well developed all through the area, viz. the "laminated sandstones" of Mr. Hislop¶, the Kámthi group of the Geological Survey**. Unfortunately the valleys of the Godavery and its tributaries, the Pránhíta, the Pain Gunga, the Wain Gunga, and the Wárdha, in which the plant-bearing series occur, are much covered by later Tertiary and recent alluvial deposits; so that the visible sections are few and small, and the thickness of the groups has not been ascertained.

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* Mem. G. S. I. vol. ii. p. 176.

† Originally termed Upper Dámúdá; but this name, being based on an erroneous assumption, has been abandoned.

‡ Mem. G. S. I. vol. ii. p. 325.

§ Ibid. vol. x. Art. 2.

|| *Op. cit.* vol. x. Art. 2, p. 27.

¶ Quart. Journ. Geol. Soc. 1855, vol. xi. pp. 370, 373.

** Mem. G. S. I. vol. ix. Art. 2, p. 6.

The plant-remains obtained from the Kámthi group by Mr. Hislop have been figured and described by Sir Charles Bunbury[*], who identified the most abundant fossil as *Glossopteris Browniana*, identical with that of the Ràniganj group of Bengal. The *Vertebraria* (*V. indica*) and the *Phyllotheca* (*P. indica*) are also identical[†]. But other characteristic plants of the latter formation, viz. *Sphenophyllum* (*Trizygia*) and *Schizoneura* (*Zeugophyllites*) are absent[‡]. On these grounds, as well as on that of their position, Mr. W. T. Blanford regards the Kámthis either as the Central-Indian representatives of the Ràniganj group of Bengal, or as intermediate between this and the Panchéts. The beds at Mángli, in which Mr. Hislop found *Brachyops laticeps*, Owen, and *Estheria mangaliensis*, Jones, with the teeth and scales of Ganoid fishes, are considered by Mr. Blanford to be the upper beds of this group; and *E. mangaliensis* has been identified, though doubtfully, with the species occurring in the Panchéts of Bengal, in which also occur Labyrinthodont remains &c. On these grounds, and partly on that of the greater lithological resemblance of the Kámthi to the Panchéts, Dr. Oldham considers[§] these two groups to be more nearly related to each other than to the Ràniganj group of Bengal.

The beds of Malédi, however, which overlie the Kámthis, are regarded by both as Panchéts. In these occur *Ceratodus*[||] and *Hyperodapedon*[¶], both Triassic genera in Europe, though it must not be forgotten that two species of the former are now living in Australia[**].

The geology of the Godavery valley has not yet been worked out in detail; but the officers of the Geological Survey are, I believe, agreed in regarding the Kóta beds, in which were found the remains of *Lepidotus* and *Æchmodus*[††], as probably more recent than any of the above.

V. Representatives of the Ràjmahál group have only lately been met with[‡‡] in the Godavery basins; and no description of them has yet been published; but plant-beds containing *Palæozamiæ*, some of which Dr. Oldham[§§] has identified with Cutch species, occur in Trichinopoly[||||], underlying the cretaceous rocks of that district, and also covering a large area of the plains of the Payen Ghát, west of Madras[¶¶]. In the former region they have afforded no marine fossils; but they appeared to me[***], both on stratigraphical and lithological grounds, to be not very widely separated in time from the cretaceous rocks immediately overlying them (the Ootatoor group),

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[*] Quart. Journ. Geol. Soc. 1861, vol. xvii. p. 325.

[†] W. T. Blanford, Mem. G. S. I. vol. ix. Art. 2, p. 34.

[‡] Ibid. p. 35.

[§] Introduction to the Gazetteer of the Central Provinces, p. xxxiii; also Rec. G. S. I. vol. iv. p. 73.

[||] Oldham, Mem. G. S. I. vol. i. p. 295.

[¶] Huxley, Quart. Journ. Geol. Soc. 1869, vol. xxv. p. 141.

[**] Nature, vol. iv. pp. 406, 428, 447.

[††] Egerton, Quart. Journ. Geol. Soc. vol. vii. p. 273, and vol. x. p. 371.

[‡‡] Annual Report G. S. I. for 1873.

[§§] Mem. G. S. I, vol. iv. Art. 1, p. 50.

[||||] *Vol. et loc. cit.* p. 39.

[¶¶] Foote, Mem. G. S. I. vol. x. Art. 1, p. 63.

[***] Mem. G. S. I. vol. iv. p. 47.

which Dr. Stoliczka has ascertained to be of Middle Cretaceous age[*]. But they do not belong to the Cretaceous series, being overlapped by the Ootatoor group, so that they peep out only at one or two places at its base. Near Madras they are more widely developed, and Messrs. King and Foote have found beds with marine fossils intercalated with them, of which they give the following generic list[†]:—

Fish-scales (undet.).
Ammonites, two or three species.
Belemnites?
Patella?
Rhynchonella?
Cytherea?
Cypricardia?
Tellina?
Anatina (Thracia?).
Leda, two or three species.
Lucina?
Cultellus?
Ostrea.
Inoceramus.
Lima.
Pecten.

Unfortunately these are ill preserved, and as yet no conclusion as to their age has been deduced from them.

VI. In Cutch, however, a region long since brought to notice in the 'Transactions' of the Society[‡] by Captain Grant, the evidence of the age of the plant-beds containing *Palæozamiæ* &c. is much more clear. This interesting country has lately been surveyed and described in an elaborate report by Mr. Wynne[§]; and a very large collection of fossils has been brought together, on the description of which Dr. Waagen is engaged. Mr. Wynne divides the Jurassic series of Cutch into two groups, *upper* and *lower* (using these terms with a local signification only, and without reference to the Upper and Lower Jurassic divisions of European geology). The lower group is rich in marine fossils; and plant-remains are rare or absent. In an abstract account of the results of his examination of the Ammonites of this fauna[||], Dr. Waagen states that he distinguishes eighty species; and on the evidence afforded by them he provisionally correlates the several beds of Mr. Wynne's lower group[¶] with European formations ranging from the Bath Oolite to the Étage Tithonien and Upper Kimmeridgian. It is the upper group of Mr. Wynne's division that contains the greater part of the plant-beds. The demarcation of the two groups is not very definite. Mr. Wynne states[**] that between the beds which contain distinct and well-preserved plants, and the highest marine fossiliferous beds of the lower group, intervenes a considerable thickness of beds with ill-preserved plants, and "the indefinite boundary between the lower and upper groups may be drawn anywhere through them." There is, however, "a broadly marked difference between the general character of the lower and upper groups of the formation." The latter is probably freshwater or estuarine. Only in the western part of Cutch are marine fossils found in the upper group, "some of which, according to Dr. Stoliczka, possess peculiar interest from their relations to South-African forms"[††]. The whole

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[*] Pal. Ind. ser. iii., v., vi., &c.

[†] Mem. G. S. I. vol. x. Art. 1, p. 107.

[‡] Vol. v. ser. 2, p. 289.

[§] Mem. G. S. I. vol. ix. art. 1.

[||] Rec. G. S. I. vol. iv. p. 89.

[¶] *Loc. cit.* p. 101.

[**] *Op. cit.* p. 51.

[††] *Op. cit.* p. 52.

thickness of the Jurassic series is estimated at 6300 feet, of which 3000 feet belongs to the upper group.

The facts above given suffice to establish approximately the age of the Cutch representatives of the highest members of the plant-bearing series, as being probably not older than the youngest member of the Jurassic formation—the Tithonian. The evidence of the Trichinopoly plant-beds, as far as it goes, is corroborative; and it may be mentioned that the lower members of the Cretaceous series themselves, though not containing leaf-remains, abound in fragments of wood, which Dr. Thomson recognized as Cycadaceous[*]. The stratigraphical relations of the Trichinopoly and Cutch plant-beds, apart from the palæobotanical evidence of their contents, indicate that they belong to about the same geological horizon, even if not absolutely equivalent; and on this point we may expect further evidence when the associated marine fossils shall have been fully worked out. Meanwhile they may be regarded as probably Tithonian, possibly of Wealden age. This being determined, the identity of some of the characteristic plants in these and the Jabalpúr and Rájmahál rocks of Central India and Bengal justifies the inference that these latter are also approximately of similar age; and, indeed, the former cannot be much newer, since they are overlain unconformably by the Laméta group, with which Mr. W. T. Blanford identifies[†] the fossiliferous limestones of Bágh, which contain marine fossils of a Lower Cretaceous type[‡]. Some bones, apparently Reptilian, have been found in these Laméta-beds near Jabalpúr, but too imperfect for determination[§].

The age of the lower groups is a much more difficult question. The general opinion, deduced chiefly from the fossils sent home by the late Mr. Hislop (from the Kámthi and Panchét rocks), appears to be that they belong to the lower part of the Mesozoic series; but, as Dr. Oldham has remarked, this opinion appears to have been influenced very much by the supposed Oolitic affinities of the genus *Glossopteris*. This view was combated by Dr. Oldham in the 2nd volume of the 'Memoirs of the Geological Survey'[||], when he showed that the plants from the European Oolites referred to that genus have no claim to be so considered, and consequently that any inference of the Jurassic age of the Coal-bearing rocks of Bengal based on such supposed affinities is invalid. Sir Charles Bunbury mentions[¶] one *Phyllotheca* as occurring in the Oolitic rocks of Italy, on the authority of Baron de Zigno; but while inclining to the opinion that the Kámthi rocks are Mesozoic, he insists but little on the evidence of the plant-remains, and concludes that, "such as it is, it might be outweighed by the discovery of a single well-marked and characteristic fish, shell, or coral."

In considering the question of age we must be careful to bear in

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[*] Mem. G. S. I. vol. iv. art. 1. p. 49.

[†] Mem. G. S. I. vol. vi. art. 4, p. 56, and vol. ix. art. 2, p. 36.

[‡] Duncan, Quart. Journ. Geol. Soc. vol. xxi. p. 349.

[§] Mem. G. S. I. vol. ii. p. 199.

[||] See p. 328.

[¶] Quart. Journ. Geol. Soc. vol. xvii. p. 344.

mind that we have to deal with a series of deposits of very considerable aggregate thickness. It has been shown that in the Dámúdá fields, omitting the upper sandstones, which both lithologically and by their position would seem to represent some part of the Mahádéva series, we have a thickness of 10,700 feet; and in the Sátpúra field, omitting the groups five to eight, which are probable equivalents of the former, we have an equal thickness (10,600 feet), making a total maximum of 21,300 feet of deposits, in which are several interruptions (evidenced by unconformity), though not perhaps of any great amount. There is certainly, then, no need, on stratigraphical grounds, to compress the plant-bearing series into very narrow limits of time; and we must be careful not to confuse the fossil evidence, such as it is, that is afforded by the different groups.

The Panchét and Ráníganj groups with the Kámthi group, which we may assume provisionally to be of intermediate age to the two former, are those the fossil evidence of which is the least imperfect. Following Mr. Medlicott, I shall regard the Bijóri group as the local equivalent of the Ráníganj-beds of Bengal, though it may perhaps with equal probability be regarded as the equivalent of the Kámthi rocks.

The Bijóri and Ráníganj-beds together have furnished the Carboniferous genus *Archegosaurus* and plant-remains which, when compared with those of European formations, admittedly throw very little light on the question of age. The Kámthi group has yielded a Labyrinthodont not nearly allied to any European form, an *Estheria*, and plant-remains in part identical with those of the Ráníganj-beds. The Panchét group has furnished *Hyperodapedon* and *Ceratodus*, both genera of Triassic affinities; also two new genera of Labyrinthodonts, a *Dicynodon*, and a fragment of a Thecodont saurian. With respect to these last, Professor Huxley remarks, "at present I think there is no evidence to decide whether they are older Mesozoic or newer Palæozoic;" and in another paper on *Hyperodapedon* he guardedly observes, "even now that *Hyperodapedon* is distinctly determined to be a Triassic genus, the possibility that it may hereafter be discovered in Permian, Carboniferous, and even older rocks remains an open question in my mind. Considerations of this kind should have their just weight when we attempt to form a judgment respecting the Reptiliferous strata of the Karoo formation in South Africa, and of Malédi and elsewhere in India." Perhaps the same caution, with an opposite tendency, may be observed with respect to the evidence afforded by *Archegosaurus*.

The evidence of age, then, afforded by a comparison of the fossil contents of these formations with those of European rocks leads only to somewhat vague conclusions. It indicates little more than that these formations probably range somewhere between the Carboniferous horizon and that of the Trias. The occurrence of *Archegosaurus* would tend to depress the Bijóri and with it the Ráníganj group to a Carboniferous horizon, and that of *Hyperodapedon* and *Ceratodus* to raise the Panchét group to a Triassic horizon, in which case the Kámthi group might be supposed to represent the Permian formation. But the correlation of these groups *inter se* is too indeterminate to allow of any great weight being given even to this slender evidence.

The resemblance of the plants of the Indian and Australian (N.S. Wales) Coal-fields has long been known and repeatedly noticed in the pages of the Society's Journal and elsewhere. In both countries *Glossopteris*, *Phyllotheca*, *Vertebraria*, and *Zeugophyllites* [or *Schizoneura*] are among the commonest and most characteristic forms, the species being, in part at least, identical. Thus *Glossopteris Browniana* is recognized as common to the two countries by all describers; *Phyllotheca indica*, Bunbury, is apparently identical with *P. Hookeri*, McCoy; and the *Vertebraria* also appears to be the same, whatever may be nature of that remarkable fossil. Dr. Oldham also mentions* that *Pecopteris Laidlayana*, Royle, is identical with *P. australis*, Morris, and that one species of *Sphenopteris* is certainly common to the two countries. How much further this identity of the two floras may extend can only be known fully when both shall have been worked out in detail; but our present knowledge justifies the conclusion that their coincidence is remarkably great†, seeing that the two localities are separated by a distance of 5550 miles. We must, I think, further conclude that the two formations cannot be far separated in geological time, while their geographical connexion and the similarity of their physical conditions must at one time have been very close.

Now the testimony of the Rev. W. B. Clarke, Mr. Jukes, and Mr. Daintree, all of whom have examined *in situ* the N.S. Wales rocks or their Queensland equivalents, is to the effect that the plant-bearing beds belong to the same formation as the marine fossiliferous beds of Stony Creek &c., the fossils of which, described by Morris and McCoy, prove them to be of Carboniferous age. Perhaps the most distinct evidence on this point is that furnished by the sections of two coal-pits at Stony Creek, on the north side of Harper's Hill, given by Mr. Clarke in the 6th volume of the 'Transactions' of the Royal Society of Victoria. These shafts were sunk through beds full of *Spirifer*, *Fenestella*, *Conularia*, *Orthoceras*, &c., lying above beds of coal and "blue clod" full of *Glossopteris*, *Phyllotheca*, and leaves of *Nœggerathia* [*Schizoneura* ?]. Mr. Daintree, too, describes‡

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* Mem. G. S. I. vol. ii. p. 328.

† The following generic list of plants from the N. S. Wales field, compiled from the lists of Morris, Dana, and McCoy, may be compared with Dr. Oldham's list of the Dámúdá plants given in the text, p. 520:—

Sphenophyllum	1 species.	Otopteris...............	1 species.
Vertebraria...............	1 ,,	Zeugophyllites	1 ,,
Phyllotheca...............	3 ,,	Clastoria	1 ,,
Cyclopteris	6 ,,	Anarthrocanna	1 ,,
Pecopteris	2 ,,	Cystocerites	1 ,,
Glossopteris	6 ,,	Austrella...............	1 ,,
Sphenopteris	6	Confervites	1 ,,

‡ Quart. Journ. Geol. Soc. vol. xxviii. p. 286.

a similar succession of beds on the Bowen river, in Queensland, where freshwater shales with fragments of *Glossopteris* are overlain by *Productus*- and *Spirifer*-beds. He certainly states, "I have never been able to find the flora and fauna unmistakably represented in the same bed;" but seeing that the plant-beds are apparently in all cases of freshwater origin, such an association is not to be expected. In the face of this specific evidence, supported by the general testimony of Mr. Clarke and Mr. Jukes, I am unable to see any sufficient ground for refusing to admit that the age of the Australian plant-beds is the same as that of the upper portion of the marine formation containing Carboniferous fossils. Dr. Oldham (long before the publication of Mr. Daintree's corroborative evidence) arrived at a similar conclusion*, and inferred that "the Dámúdá system of our Indian classification will be found to represent (if not in its entirety, certainly in part) the Permian system of European geologists." But he thinks further that it will also be found to include "a large portion of the Carboniferous epoch," and is disposed to correlate the Talchír group with the Wollongong Sandstones of Australia, remarking on "the strikingly curious identity in the lithological character and structure of the rocks."

I should myself be disposed to concur in this conclusion, were it not for the evidence of glacial action afforded by the oldest deposits of the Talchír group, which, taken in conjunction with Professor Ramsay's discovery of the glacial character of the Lower Permian breccias, irresistibly suggests the contemporaneity of the two formations.

At the base of the Talchír group, wherever these rocks have been met with, occurs that remarkable boulder-bed first noticed in Talchír, and described in the 1st volume of the 'Memoirs of the Geological Survey.' Its character appears to be very constant. It consists of blocks of all sizes up to 42 feet in circumference†, imbedded in a fine silty (sometimes sandy) matrix, often of a green colour and finely stratified. The blocks have in some cases certainly been transported from a distance of some miles‡; but this is not in general easy to ascertain, as the older rocks are frequently of very uniform character over large areas. When this bed was first described (in Talchír) in 1856, Mr. W. T. Blanford suggested its glacial origin and the transport of the boulders by ice, seeing that any movement of water sufficiently violent to disturb the imbedded boulders must infallibly have swept away the fine silty matrix. He suggested the agency of ground-ice, and ventured to predict§ that further examination would probably end in the discovery of groovings and scratchings on these surfaces. This view of the origin of the boulder-bed for many years found but little favour; but in 1872 Dr. Oldham and Mr. Fedden exhumed from the bed, in the neighbourhood of the Godavery, "large masses of foreign or transported rocks, the surface of which was polished as perfectly as marble by a lapidary—this polished surface being beautifully scored and furrowed in

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* Mem. G. S. I. vol. iii. p. 207.

† Mem. G. S. I. vol. vi. art. 3, p. 7.

‡ Rec. G. S. I. vol. vi. p. 28.

§ Mem. G. S. I. vol. i. p. 49.

parallel and straight lines, precisely similar to the scoring, furrowing, and polishing which rocks carried down by glaciers and ground-ice are so well known to exhibit. And, further, the hard Vindhyan limestone on which this Talchír boulder-bed was laid, was also found to be scored in long parallel lines wherever the upper surface was freshly exposed by the recent removal of the overlying rocks" [*]. One of the exhumed boulders is now in the Geological Museum of Calcutta; and I think that an inspection of it would convince the most sceptical of its glacial character.

No similar bed has been described in Australia, where the beds underlying the coal are of marine origin; but the Karoo formation of South Africa, which resembles the Indian Dámúdá series in containing *Glossopteris* and *Phyllotheca*, has at its base a bed termed the "Claystone Porphyry" by Bain [†], the "Trap Breccia" by Wyley [‡], the characters of which evidently closely resemble those of the Talchír "boulder-bed." This resemblance has already been pointed out by Mr. Griesbach [§]; but he has fallen into the error of confounding the Talchír boulder-bed with one that occurs at the base of the Trichinopoly (Rájmahál) plant-beds, which differs from the former in lithological characters, and is probably an ordinary coast-conglomerate. The Karoo boulder-bed, according to Dr. Sutherland [‖], is not, as supposed by its earlier describers, a volcanic breccia [¶], but affords distinct evidence of its glacial origin. He describes it as consisting of a greyish blue argillaceous matrix, containing fragments of granite, gneiss, &c. from the dimensions of sand-grains up to blocks measuring 5 or 6 feet across. They are smoothed, as if they had been subject to attrition in a muddy sediment, but not rounded like sea-worn boulders. The matrix is compact and tenacious; it has a rude disposition towards stratification, the general appearance being that of a clay which has been deposited by water and afterwards metamorphosed. In some places it is ripple-marked. In Natal the bed rests on Old Silurian Sandstones, which in many cases are deeply grooved and striated. The thickness of this bed, as well as its extent, much exceeds that of the Indian "boulder-bed," since it is as much as 800, sometimes 1200, feet thick; and it everywhere underlies the Karoo formation, which appears to cover all the interior of South Africa. I defer the discussion of the question whether these two beds are coeval, until I shall have noticed the palæontological evidence of the higher beds of the series.

The succession given by Mr. Wyley [**] is as follows (omitting his

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[*] Mem. G. S. I. vol. ix. art. 2, p. 30.

[†] Trans. Geol. Soc. ser. ii. vol. vii. p. 185.

[‡] Quart. Journ. Geol. Soc. vol. xxiii. p. 172.

[§] *Loc. cit.* p. 60.

[‖] Quart. Journ. Geol. Soc. vol. xxvi. p. 514.

[¶] It is a curious coincidence that Mr. King, in describing the Talchír boulder-bed near Kámáram, in the Nizam's territory, south of the Godavery, has fallen into what appears to be a similar error. He speaks of the matrix as volcanic muds and ashes, but does not adduce any corroborative evidence of volcanic action during the Talchír period; and in common with my brother, who has had a very extensive experience of these rocks, I cannot but think it probable that Mr. King has mistaken its lithological character.

[**] Quart. Journ. Geol. Soc. vol. xxiii. p. 172.

Lower Ecca beds beneath the "Trap breccia," which, from the evidence of Bain, Griesbach, and Sutherland, and, indeed, Mr. Wyley's own description, appear not to belong to the Karoo series):—

1. The Stormberg beds	1800 feet.
2. The Beaufort beds	1700 „
3. The Koonap beds	1500 „
4. The Upper Ecca beds	1200 „
5. The "Trap Breccia" (boulder-bed)	500 to 800 „

Below these are the Lower Ecca shales and a great thickness of sandstone containing remains of *Lepidodendron*, resting on the formation which has been determined by Lonsdale and Salter[*] to be of Devonian age. I am not aware whether the *Lepidodendron* remains have been determined to be of this or of Carboniferous age.

It is unnecessary to recapitulate the characters of the several members of the Karoo series, as they have been clearly summarized by Prof. T. Rupert Jones[†] in Mr. Tate's paper on some fossils from South Africa. It is only necessary to notice that *Glossopteris Browniana* and another species of the same genus, with a *Phyllotheca* much resembling *P. indica*, Bunbury, occur in the Beaufort beds, where they are associated with several species of *Dicynodon* &c.; while from beds which are spoken of as higher in the same group were obtained several other species of *Dicynodon*, *Microlophis Stowii*, Huxley, *Galesaurus*, and *Cynochampsa*. It is these Beaufort beds which bear the greatest analogy to the Panchét and Kámthi groups of India. The Stormberg beds, which overlie them, contain, besides a *Dicynodon*, several species of Dinosaurian reptiles, a group which, I believe, in Europe is not known to range below the Trias.

Mr. Tate assigns the whole Karoo formation to the Trias; but even if the probability of this conclusion be admitted as regards the fossiliferous Beaufort and Stormberg beds, there does not seem any good reason for refusing to admit that the lower groups may be of Permian age.

As above stated, the Kámthis and Panchéts show considerable analogy with the Beaufort beds:—the first by the abundant presence of *Glossopteris Browniana*, and a *Phyllotheca* probably identical, and also of a Labyrinthodont nearly allied to *Microlophis Stowii*; the second by that of a Dicynodont, being the only known case of the occurrence of this form out of South Africa. These cases of identity, though absolutely few, are very great in proportion to the total number of fossil forms yet described from the formations in question. If, then, we admit provisionally this correlation, the Dámúdá series would correspond in position with the Koonap beds, and the Talchírs with the "Ecca conglomerate" or "Trap breccia;" but if there be no other evidence than their similarity of relative position, I should attribute but very little weight to such a correlation.

The question then arises, Can the evidence of glacial conditions afforded both by the "Ecca conglomerate" and the "Talchír boulder-bed" be taken as evidence of contemporaneity with each other and

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[*] Trans. Geol. Soc. sér. ii. vol. vii. p. 224.

[†] Quart. Journ. Geol. Soc. vol. xxiii. p. 142.

with the Lower Permian breccias of Great Britain, which, as far as palæontological evidence goes, occupy somewhat the same position in the general geological sequence? This is so difficult a question in the present state of our knowledge of terrestrial and cosmical physics, that it is only with much diffidence that I venture to put forward the following considerations, in which, since my argument turns on the sum of probabilities, I must perforce have recourse to such facts as may be furnished by that later glacial period, the evidence of which is more complete than of that of Permian times.

It is now well known that evidence of greatly extended glacial conditions in the latest Tertiary times is not restricted to Europe, nor even to the temperate zone. In Syria Dr. Hooker has shown that glaciers formerly existed in Lebanon*; in the Sikkim Himalaya Mr. W. T. Blanford has adduced proofs of their existence down to a level of 6000 feet†, and Mr. H. B. Medlicott‡ and Mr. Theobald§ in the Kangra valley, of the Western Himalaya, down to 3000 feet (or, according to Mr. Theobald, 2000 feet) above sea-level. Quite recently Major Godwin-Austen, whose experience in the lofty mountains of Northern Kashmír has certainly familiarized him with the effects of glacial action, has observed moraines in the Naga Hills of Eastern Bengal down to a level of 4500 feet above the sea. This, be it remembered, is in latitude 26°; and the hills which produced these glaciers do not exceed 10,000 feet in height.

Mr. Medlicott|| and, subsequently, Mr. Theobald¶ have suggested that the Himálayan chain has undergone great subsidence, according to the latter writer to an extent of 12,000 or 15,000 feet; and Mr. Theobald appears to consider that an additional elevation to this extent would suffice to produce glaciers that would "from the magnitude of their drainage-area" descend to 1500 feet above sea-level. Mr. Theobald further considers that the great glaciers, the effects of which he describes (including one in the Sutlej valley 350 miles long), were antecedent to the formation of the Sivalik [Miocene?] group. The whole discussion is too long to be quoted here; and I must therefore refer readers to the original papers in the publications of the Geological Survey of India. I can only say that I have failed to be convinced, and that it does not appear to me that any evidence has been advanced to show that the great extension of the glaciers (which I admit) was pre-Sivalik. With regard to the sufficiency of great elevation to produce that extension, I am equally unable to coincide with Mr. Theobald. The Himálaya even now dries the winds pretty effectually up to a height of 20,000 feet, and the residual vapour between 20,000 and 35,000 feet, even supposing it to be brought in the same volume as at present, would hardly be such as to produce a glacier in the Sutlej valley 350 miles

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* Nat.-Hist. Review, vol. ii. p. 12.

† Journ. As. Soc. Beng. vol. xl. pp. 379, 393. They may have extended lower; but the excessive rainfall of the southern slopes of the Sikkim Himálaya and the chemical disintegration of the rocks are very unfavourable to the preservation of glacier-markings and moraines.

‡ Mem. G. S. I. vol. iii. art. 4, p. 155.

§ Rec. G. S. I. vol. vii. p. 87.

|| Mem. G. S. I. vol. iii. art. 4, p. 170.

¶ Rec. G. S. I. vol. vii. p. 97.

long. But such a mountain-range would offer an obstruction to the passage of the winds, such as would certainly diminish their volume; and it may be questioned whether the total precipitation would be greater than it now is. Some extension of the glaciers would probably result were the quantity of vapour brought to these mountains much greater than is now brought; and there may have been some increase when, as Mr. W. T. Blanford has shown*, the present deserts of Balúchistán and Persia were occupied by great inland seas or lakes, and when, therefore, the westerly winds were damper than they now are. But in the case of the Sikkim Himálaya the outer slopes now receive some of the heaviest rainfall in the world†, yet the glaciers of the snowy chain do not descend below 14,000 feet. Even, then, if the assumed former elevation of the Himálaya were less purely hypothetical than I think it is, it seems inadequate to explain the glacier phenomena of these mountains, and it would have little or no application in the case of the Naga Hills, which form no part of the Himálaya.

If this solution of the problem be rejected, there remains the supposition that the temperature of the whole region was formerly very much lower than that which now prevails. The Mer de Glace, in the Western Alps, descends to 4000 feet, this part of the Alps being situated about on the isotherm of 55°. Sibsagar, in the Asám valley, north of the Naga hills, is on the isotherm of 75°·5. To produce glaciers that should reach down to 4500 feet in these hills, we should then require a diminution of nearly 20 degrees in the mean annual temperature; and at least an equal reduction would be necessary to prolong the glaciers of the Sutlej basin down to 2000 feet, or even 3000 feet. I am unable to conceive any change of the local physical geography, consistent with the existence of the Himálayan chain, which should induce such a revolution of the climate as is here required. The theory of Mr. Croll seems to me equally inadequate, since the change in the mean annual temperature which, on his showing, might result from the varying eccentricity of the earth's orbit and the precession of the equinoxes, must diminish rapidly in low latitudes, becoming zero at the equator. Moreover, if the glacial phenomena of Patagonia, described by Mr. Darwin, are to be assigned even approximately to the same period as those of Europe (which, if not proved, has certainly not been disproved), his theory would, as I understand it, necessarily fail to account for the phenomena.

The questions of terrestrial physics involved in this inquiry are too vast and complicated to be entered upon here; and it cannot perhaps be determined on the present evidence whether the diminution of temperature during the glacial period affected one hemisphere only, or both simultaneously. But in the present state of the question it seems to me that such hypotheses as have been put forward

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* Quart. Journ. Geol. Soc. vol. xxix. p. 493.

† At Buxa fort, north of Goalpára, the average of four years was 256 inches. At Rangbi, within the hills of Sikkim, that of six years was 175 inches; and at Darjiling that of ten to thirteen years was 125 inches.

to explain its phenomena have not such presumption of adequacy as to exclude the probability that the principal cause was one of general incidence and is yet to seek. Whether, as some astronomers have speculated, our sun is a variable star of long period, or whether some other cosmical cause as yet undetected has been operative in producing these great changes of climate, is rather a question for astronomers than geologists; but whatever the cause, to my mind, the balance of probability is in favour of these great oscillations of climate being general and not local merely.

I am not unmindful of Professor Tyndall's objection, illustrated by the case of the still, viz. that to increase our products of condensation we must increase the fire under our boiler. This is of course true; but it does not seem to me that the assumption of wide-spread glaciation is inconsistent with a great reduction in the total amount of condensation in the unit of time. We can spare all the tropical and subtropical rains, provided that we have the residue that now falls, in part as snow, in temperate and Arctic regions, and a decrease of liquefaction such as would allow of a great depression of the snow-line. If the conditions of Spitzbergen were transferred to the British isles, and those of the Alps to the Himálaya, the total precipitation per annum in each of these regions would be greatly reduced. In Arctic regions, during the period of maximum cold, the precipitation might perhaps be infinitesimal; and during such time the glaciation of the rocks might then be altogether suspended; but supposing the change of climate to progress slowly, every zone of the earth, down to the tropical limit of the ice, would be successively glaciated—first during the period of increasing cold, and again during its decrease; and this is all that the circumstances of the case demand.

If the probability be admitted that the reduction of temperature evidenced by the glaciation of Postpliocene times was general, we may by analogy argue that such was also probably the case in early Permian times, in which case the physical evidence of glaciation becomes of at least equal value with palæontological evidence in questions of correlation, perhaps even of greater value when it is a question of correlating formations in very distant regions; and since the palæontological and stratigraphical evidence warrants the conclusion that the Ecca conglomerates, the Talchír boulder-bed, and the Permian breccias of England are not very far distant in time, I think we may provisionally refer them with some probability to the same glacial period.

The comparatively small thickness of the Talchír boulder-bed in latitudes 17° to 23°, as compared with the great thickness of the Ecca conglomerate in latitudes 30° to 32°, would perhaps imply a shorter duration of glacial conditions in the former; but mere thickness is, of course, no safe criterion of duration. Moreover, as suggested by my brother, ground-ice in the winter time would be quite competent to produce all the effects to be accounted for in the Indian area, though in Natal Dr. Sutherland appears to consider that the evidence is in favour of a general glaciation of the country.

The assumed return of warmth during Permian times, after a general reduction of temperature, would be eminently favourable to that extension of similar or nearly allied forms of life which we have evidenced in the Australian, Indian, and South-African plant-beds, provided the distribution of the land were such as to admit of their diffusion, a subject which I shall discuss presently. The prevalence of a cold climate would also help to explain the comparative absence of animal and vegetable life from the deposits of the Talchír period—deposits which by their lithological character seem well fitted to receive and preserve such remains. This Koonap group in South Africa would seem to be equally deficient in fossil remains, these beds in lat. 30° to 32° being the supposed representatives of our Dámúdá series in lat. 17° to 23°, in which a flora abundant in individuals, but poor in species, at that time flourished. With regard to the Australian plant-beds I see no evidence to show whether they preceded or followed the glacial period. Australia may have been the home in later Carboniferous times of a flora which was afterwards driven towards the equator, and subsequently, on the return of a genial climate, spread to Africa and India; or since, for aught we know, the marine forms *Orthoceras, Eurydesma, Spirifer, Conularia,* and *Fenestella,* &c. may have been fitted to live in cold seas; the beds containing them may be in part of early Permian age: this supposition gains some support from the lithological resemblance of the rocks containing them to those of the Talchír group, a resemblance noticed by Dr. Oldham, and which implies some similarity of physical conditions. On this supposition *Glossopteris, Phyllotheca,* &c. may have spread to Australia in Permian times, and the extinction of the preceding Devonian flora (*Lepidodendron* &c.) may have occurred during the glacial period. Perhaps the extinction of the Carboniferous flora of Europe may have been due to the same cause.

On the review of all the probabilities (and partial probabilities are the only guides we have), I am inclined, then, to relegate the lowest groups of the Indian plant-bearing series to Permian times, and to correlate them with the lower groups of the Karoo formation of Africa and, possibly, the Wollongong sandstones and Newcastle-coal series of Australia. But I admit that the validity of this view depends in a very great measure on that of my speculation that there was a general decrease of temperature over the earth's surface between the Carboniferous and Permian epochs; and this must stand or fall by the evidence of future investigation.

The affinities between the fossils, both animals and plants, of the Beaufort group of Africa and those of the Indian Panchéts and Kámthis are such as to suggest the former existence of a land connexion between the two areas. But the resemblance of the African and Indian fossil faunas does not cease with Permian and Triassic times. The plant-beds of the Uitenhage group have furnished eleven forms of plants, two of which Mr. Tate has identified with Indian Rájmahál plants. The Indian Jurassic fossils have yet to be described (with a few exceptions); but it has already been stated that Dr. Stoliczka was much struck with the affinities of certain of the

Cutch fossils to African forms; and Dr. Stoliczka and Mr. Griesbach have shown that of the Cretaceous fossils of the Umtafuni river in Natal, the majority (twenty-two out of thirty-five described forms) are identical with species from Southern India. Now the plant-bearing series of India and the Karoo and part of the Uitenhage formation of Africa are in all probability of freshwater origin, both indicating the existence of a large land area around, from the waste of which these deposits are derived. Was this land continuous between the two regions? and is there any thing in the present physical geography of the Indian Ocean which would suggest its probable position? Further, what was the connexion between this land and Australia, which we must equally assume to have existed in Permian times? And, lastly, are there any peculiarities in the existing fauna and flora of India, Africa, and the intervening islands which would lend support to the idea of a former connexion more direct than that which now exists between Africa and South India and the Malay peninsula. The speculation here put forward is no new one. It has long been a subject of thought in the minds of some Indian and European naturalists, among the former of whom I may mention my brother and Dr. Stoliczka, their speculations being grounded on the relationship and partial identity of the faunas and floras of past times, not less than on that existing community of forms which has led Mr. Andrew Murray, Mr. Searles V. Wood, jun., and Professor Huxley to infer the existence of a Miocene continent occupying a part of the Indian Ocean. Indeed, all that I can pretend to aim at in this paper is to endeavour to give some additional definition and extension to the conception in its geological aspect.

With regard to the geographical evidence, a glance at the map will show that from the neighbourhood of the west coast of India to that of the Seychelles, Madagascar, and the Mauritius extends a line of coral atolls and banks, including Adas bank, the Laccadives, Maldives, the Chagos group, and the Saya de Mulha, all indicating the existence of a submerged mountain-range or ranges. The Seychelles, too, are mentioned by Mr. Darwin* as rising from an extensive and tolerably level bank, having a depth of between 20 and 40 fathoms; so that, although now partly encircled by fringing reefs, they may be regarded as a virtual extension of the same submerged axis. Further west the Cosmoledo and Comoro Islands consist of atolls and islands surrounded by barrier reefs; and these bring us pretty close to the present shores of Africa and Madagascar. It seems at least probable that in this chain of atolls, banks, and barrier reefs we have indicated the position of an ancient mountain-chain, which possibly formed the back-bone of a tract of later Palæozoic, Mesozoic, and early Tertiary land, being related to it much as the Alpine and Himálayan system is to the Europæo-Asiatic continent†,

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* 'Coral Reefs,' Appendix, p. 185.

† This idea, based of course on Mr. Darwin's discovery, has been also specifically suggested by Mr. Andrew Murray (see the 'Geographical Distribution of Mammalia,' p. 25), and by Mr. Searles V. Wood, jun. (see Phil. Mag. 1862, vol. xxiii. p. 388).

and the Rocky Mountains and Andes to the two Americas. As it is desirable to designate this Mesozoic land by a name, I would propose that of Indo-Oceania. Professor Huxley has suggested, on palæontological grounds [*], that a land connexion existed in this region (or rather between Abyssinia and India) during the Miocene epoch. From what has been said above, it will be seen that I infer its existence from a far earlier date. With regard to its depression, the only present evidence relates to its northern extremity, and shows that it was, in this region, later than the great trap-flows of the Dakhan. These enormous sheets of volcanic rock are remarkably horizontal to the east of the Gháts or the Sahyádri range, but to the west of this they begin to dip seawards, so that the island of Bombay is composed of the higher parts of the formation [†]. This indicates only that the depression to the westward has taken place in Tertiary times; and to that extent Professor Huxley's inference, that it was after the Miocene period, is quite consistent with the geological evidence.

It is well known that in the Indian fauna of today there is a considerable intermixture of forms which are identical with those of North Africa, or nearly related to them. Among them may be instanced the Lion, Hyæna, Jackal, Leopard, the true Antelopes, and the Gazelles, the common Sand-Grouse (*Pterocles exustus*), and the Indian Bustard. There are also several land mollusca, a group which is of especial value in questions of the distribution of faunas, viz. several species of *Bulimus* and *Helix*, and one of the two Cyclostomoid genera (*Otopoma*) known to occur in India. This fauna is most abundant in the dry region around the Indus; but some forms extend through the Indian peninsula, and even into Ceylon. From Western India it ranges through Persia, Arabia, and Syria, indicating clearly the route by which it has penetrated to India. It is sometimes termed the "Desert-fauna." There is also a corresponding element in the Indian flora, termed by Drs. Hooker and Thomson [‡] the "Egyptian type."

But besides this element, there is another fauna which is closely related to the forms of Tropical and Southern Africa and Madagascar, also to those of the Mauritius, Bourbon, and the Seychelles [§]. One of the most striking and familiar examples is afforded by the Lemurs, one genus of which occurs in Southern India and Ceylon, viz. the *Loris*, and two in the Malay peninsula (*Nycticebus* and *Galeopithecus*), all other members of the family (with the exception of one Javese form [||]) being indigenous to Madagascar and Tropical Africa. Another good example is afforded by the scaly Anteaters (*Manis*), which, with the African *Orycteropi*, are the sole existing representatives of the Edentata in the Old World, occurring in

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[*] Anniversary Address to the Geol. Soc. 1870, p. lvi.

[†] Wynne, "Geology of the Island of Bombay," Mem. G. S. I. vol. v. Art. 3.

[‡] Introductory Essay to the 'Flora Indica,' p. 112.

[§] This has been particularly noticed in the case of the Mammalia by Mr. Andrew Murray and Prof. Huxley.

[||] Jerdon's 'Mammals of India,' p. 16.

Guinea, Mozambique, and Sennaar and in India, whence the genus extends to China in one direction, and to Java and Borneo in another. The Asiatic and East-African forms are more nearly related to each other than to those of West Africa. A third example among Mammals is the Indian Badger (*Mellivora*), which was long considered identical with the Cape-Ratel; and though now distinguished as a species, the two forms are very closely allied. The Indian Florikin (*Sypheotides*, Lesson) is congeneric with the Tropical-African forms referred to the genus *Lissiotis* [*], Reich.; and the males have the character in common of assuming a black plumage during the breeding-season. The genus *Hypsipetes* is restricted to India and the Malayan region in Asia, and occurs also in Madagascar, the Mauritius, Bourbon, and the Seychelles.

Among the land-Mollusca are some remarkable cases of identical and allied species. One of the most striking is *Cyclotopsis* (one of the two Cyclostomoid genera of India). The Indian form ranges across the peninsula from Bombay to Orissa (*C. subdiscoideus* vel *semistriatus*, Sow.). The only other known species (*C. conoideus*, Pfr.) is from the Seychelles and the Mauritius. No species of the genus has yet been described from any other part of the world [†]. The genus *Omphalotropis* centres in the Mauritius, but ranges to Ascension on the west and to the Sandwich Islands on the east, while on the north it occurs in the Andaman Islands. *Bulimus punctatus*, Luton, is a common shell in Southern India and Ceylon, and occurs also in Zanzibar and the Mauritius. The Seychelles *Streptaxis* is closely allied to species common in Southern India, Burmah, and the Andamans. *Paludomus ajakensis*, Mor., from the Seychelles, is an outlying representative of a genus which centres in Ceylon, but has representatives in India and the Malay peninsula. One form also is said to occur in the Nile. A Seychelles *Helicina* (*H. Theobaldiana*, Nev.) is almost undistinguishable from one that occurs in the Nicobars; but this genus is not represented in India, though several forms are common in Malayana. And *Helix similaris*, Fér., occurs in the Mauritius, Seychelles [‡], and Bourbon, also in Arakan and Burmah, in China, Java, and Brazil. Lastly, *Nanina*, which is characteristically an Indian, Malayan, and Chinese genus, is represented in the Mauritius and neighbouring islands by several forms allied to those of India [§]. With respect to the plants of Madagascar and the South-Indian islands, I am unable to say what affinities they may present; but Drs. Hooker and Thomson notice the presence in India of a Tropical-African type of vegetation (distinct from the Egyptian type, which, like the "desert-fauna," is common to Persia, Arabia, &c.); and they observe, "a curious affinity

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[*] For these and the preceding examples, and several others here mentioned, I am indebted to my brother Mr. W. T. Blanford.

[†] W. T. Blanford, Ann. & Mag. Nat. Hist. 1864, vol. xiii. 3rd ser. p. 447.

[‡] It has been named *H. bourbonica* by Deshayes; but Mr. Miall considers it to be identical with *H. similaris*, in which I fully agree with him.

[§] The above are given as examples only, and they are selected as some of the most striking. A naturalist acquainted with the faunas might very greatly extend the list.

may also be traced between the vegetation of Western Tropical Africa and that of the peninsular chain," quoting, at the same time, some cases of specific identity.

Palæontology, physical geography, and geology, equally with the ascertained distribution of living animals and plants, offer then their concurrent testimony to the former close connexion of Africa and India, including the tropical islands of the Indian Ocean. This Indo-Oceanic land appears to have existed from at least early Permian times, probably (as Professor Huxley has pointed out) up to the close of the Miocene epoch; and South Africa and Peninsular India are the existing remnants of that ancient land. It may not have been absolutely continuous through the whole of this long period. Indeed the Cretaceous rocks of Southern India and Southern Africa, and the marine Jurassic beds of the same regions, prove that some portions of it were, for longer or shorter periods, invaded by the sea; but any break of continuity was probably not prolonged; for Mr. Wallace's investigations in the Eastern Archipelago have shown how narrow a sea may offer an insuperable barrier to the migration of land-animals. In Palæozoic times this land must have been connected with Australia, and in Tertiary times with Malayana, since the Malayan forms with African alliances are in several cases distinct from those of India. We know as yet too little of the geology of the eastern peninsula to say from what epoch dates its connexion with Indo-Oceanic land. Mr. Theobald has ascertained the existence of Triassic, Cretaceous, and Nummulitic rocks in the Arakan coast-range; and Carboniferous limestone is known to occur from Moulmein southwards, while the range east of the Irawadi is formed of younger Tertiary rocks. From this it would appear that a considerable part of the Malay peninsula must have been occupied by the sea during the greater part of the Mesozoic and Eocene periods. Plant-bearing rocks of Ránigan̄j age have been identified as forming the outer spurs of the Sikkim Himálaya; the ancient land must therefore have extended some distance to the north of the present Gangetic delta. Coal, both of Cretaceous and Tertiary age, occurs in the Khasi Hills, and also in Upper Assam, but in both cases associated with marine beds; so that it would appear that in this region the boundaries of land and sea oscillated somewhat during Cretaceous and Eocene times. To the north-west of India the existence of great formations of Cretaceous and Nummulitic age, stretching through Balúchistán and Persia, and entering into the structure of the North-west Himálaya, prove that in the later Mesozoic and Eocene ages India had no direct connexion with Western Asia; while the Jurassic rocks of Cutch, the Salt range, and the Northern Himálaya show that in the preceding period the sea covered a large part of the present Indus basin; and the Triassic, Carboniferous, and still more ancient marine formations of the Himálaya indicate that, from very early times till the upheaval of that great chain, much of its present site was for ages covered by the sea.

Table of Indian Plant-bearing Series and Equivalents.

INDIA.					S. AFRICA.	AUSTRALIA.	EUROPE.
CUTCH.	MADRAS.	GODAVERY.	BENGAL.	NERBUDDA.			
Upper Jurassic (of Wynne). Lower Jurassic (of Wynne).	Sripermatúr &c., Zamia beds.	Sandstones with Zamias &c.	Rájmahál group.	Jabalpúr group.	Uitenhage series.	Wollumbilla series.	JURASSIC. LIASSIC.
		Kota-beds.	Upper sandstones of coal-fields.	Bágra group. Denwa group. Pachmari group.			
		Panchéts (Malédi).	Panchét group.	Almód group.	Karoo series.	Wyanamatta group.	TRIASSIC.
		Kámthi group (Mángli).	Ránigani group.	Bijori group.			
			Ironstone shales.	Motúr group.		Hawkesbury group.	
		Barákar group.	Barákar group.	Barákar group.		Newcastle coal.	PERMIAN.
		Talchír group.	Talchír group.	Talchír group.		Wollongong sandstone (part)?	

To sum up the several views advanced in this paper:—

1st. The plant-bearing series of India ranges from early Permian to the latest Jurassic times, indicating (except in a few cases, and locally) the uninterrupted prevalence of land and freshwater conditions. These may have prevailed from much earlier times.

2nd. In the early Permian, as in the Postpliocene age, a cold climate prevailed down to low latitudes, and, I am inclined to believe, in both hemispheres simultaneously. With the decrease of cold the flora and reptilian fauna of Permian times were diffused to Africa, India, and possibly Australia; or the flora may have existed in Australia somewhat earlier, and have been diffused thence.

3rd. India, South Africa, and Australia were connected by an Indo-oceanic continent in the Permian epoch; and the two former countries remained connected (with at the utmost only short interruptions) up to the end of the Miocene period. During the latter part of the time this land was also connected with Malayana.

4th. In common with some previous writers, I consider that the position of this land was defined by the range of coral reefs and banks that now exists between the Arabian Sea and West Africa.

5th. Up to the end of the Nummulitic epoch no direct connexion (except possibly for short periods) existed between India and Western Asia.

EXPLANATION OF PLATE XXV.

Outline Map of India, showing the Distribution of the Plant-bearing Series referred to in Mr. Blanford's paper.

Discussion.

Prof. Ramsay said that he thought the age of the different beds referred to had been correctly determined by the author. He thought that there were closer relationships between the Permian and Triassic formations than is usually supposed. He referred to the time when the possibility of the occurrence of glaciation in Permian times was doubted; but erratic boulder-beds of undoubtedly Permian age had since been described as occurring in South Africa, and he thought there was a general tendency to admit the possibility of Permian glaciation. He remarked that, according to Mr. Croll, glacial periods occur at intervals, alternating on the northern and southern hemispheres every 25,000 years. The south is now under more glacial conditions than the north; and during the formation of our Boulder-clay the southern hemisphere probably had a more temperate climate. Prof. Ramsay agreed with the author in the belief of the junction of Africa with India and Australia in geological times.

Prof. T. Rupert Jones said that he wished to express his high appreciation of the masterly summary of the facts and theories relating to the wide extension of the early mesozoic fauna and flora given by Mr. Blanford in this paper, and supplemented by the results of his own personal observations on the geology of India. He referred to the still stronger evidence which the Karoo beds will probably afford when their reptiles shall have been all worked out. Their Palæoniscan fishes would form no exception to their mesozoic character, as *Palæoniscus* occurs in the English Trias. The conglomerate bed at the base of the Karoo, though described as glacial in Natal, presents peculiarly volcanic characters in other parts of South Africa. Referring to the occurrence of a Labyrinthodont in Australia, Prof. Jones dated the rise of the inquiry into the extent of Mesozoic land in the southern hemisphere from Prof. Huxley's notice of this and other Amphibians and his own observations on the range of *Estheriæ*. He thought that the Mesozoic plant-bearing and reptiliferous beds of Carolina and Virginia had very similar relations to those mentioned in the paper. In conclusion he referred to the more recent glaciation of South Africa described by Mr. Stow, and also to Mr. Belt's popular exposition of the hypothesis of bipolar glaciation, and suggested that the earth's passing through cold stellar spaces might perhaps be the real cause of glacial epochs.

Mr. Drew wished to know what were Mr. Blanford's views as to the land from which the river came that deposited the strata with which the plant-remains were associated. With such great thicknesses as 11,000 and 15,000 feet of fluviatile beds, the occurrence of which implied a corresponding amount of sinking, there must, he thought, at one time have been very high land, which was thus drained and denuded. He inquired what portion, if any, of this land now remains.

Mr. Carruthers said he thought that in South Africa there are four distinct plant-beds, and that the base-bed is higher than Permian, belonging to the Jurassic series, and probably to the Oolite.

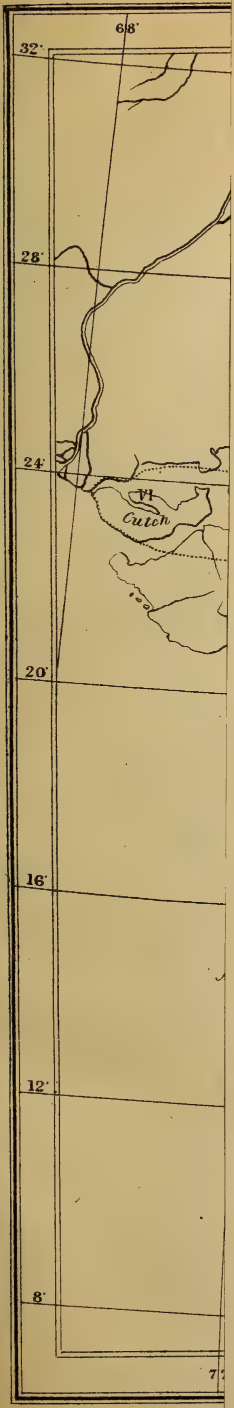
Mr. Woodward was pleased to find that the author had added further evidence, derived from the fossil flora of the Mesozoic series of India, in corroboration of the views of Huxley, Sclater, and others as to the former existence of an old submerged continent ("Lemuria"), which Darwin's researches on coral reefs had long since foreshadowed. Mr. Blanford's observations on the former existence of glaciers at much lower levels than the present snow-line of India added another valuable piece of evidence to those collected by Mr. T. Belt in Nicaragua and elsewhere. But any theory pretending to account satisfactorily for the glacial epoch, must not only explain the lower level of former glaciers in the tropics, but the former existence of a warm, temperate, and even subtropical fauna and flora in high northern latitudes, as shown by Heer, M^cClintock, and others, not to be provided for by Croll's theory or that of Balfour Stewart, but by periodic variation in the inclination of the earth's axis, as suggested by Belt, and long since by the Rev. Prof. Haughton in the Society's Journal.

Mr. Bauerman considered that the author's conclusions were in the main borne out by the evidence afforded by those portions of the Indian coal-fields with which he was acquainted. He thought, however, that there was a difficulty in the precise correlation of the

Coal-bearing series of Western India with those of Bengal, owing to the absence of the best physical horizon in the Ironstone series in the western district. From what he had seen of the Talchír sections in the Nerbudda valley, he was not inclined to agree with the author as to their glacial origin; but he was not acquainted with the other section referred to in the Godavery valley. He considered that the author's conclusion as to the age of the volcanic series of the Dakhan was confirmed by the evidence of rocks of similar character occurring in Eastern Africa on the south side of the Gulf of Aden.

Dr. MURIE thought the evidence derived from the living forms of animals was in favour of their migration to or from Africa through Arabia, but not by way of the Maldive group.

Mr. BLANFORD, in reply, remarked that the ancient continent would not furnish glaciers unless it was of very great height. He suggested that the boulders referred to might have been due to the action of winter ice.


68°
32°
28°
24°
VI
Cutch
20°
16°
12°
8°
7

OUTLINE MAP OF

INDIA

Showing the distribution of the Plant-bearing series.

Fredk Dangerfield Lith. 22 Bedford Street Covent Garden London

40. *Notes on the* GASTEROPODA *of the* GUELPH FORMATION *of* CANADA,

By HENRY ALLEYNE NICHOLSON, M.D., D.Sc., F.R.S.E., F.G.S., Professor of Natural History in the University of St. Andrews.

(Read June 23, 1875.)

[PLATE XXVI.]

THE "Guelph Formation" of Canada forms the uppermost portion of the Niagara group of American geologists, and is composed of dolomitic limestones, which have a thickness of about one hundred and sixty feet. The establishment of the formation as a distinct subdivision of the Niagara series is due to the labours of the Geological Survey of Canada (Sir William Logan, 'Geology of Canada,' p. 336). Subsequently Prof. James Hall recognized the occurrence of similar magnesian limestones lying above the Niagara limestone at the Leclaire rapids on the Mississippi river; and he expressed the opinion that they were identical with the Guelph formation of Canada (Geology of Iowa, vol. i. p. 73). At a still later period, Professor Hall detected limestones of the same mineral characters, holding the same stratigraphical position, and charged with similar fossils, at Racine and some other localities in Wisconsin (Report on the Geology of Wisconsin, p. 67). Finally, beds of the same nature and with the same organic remains have been recognized as forming the summit of the Niagara series in Northern and South-western Ohio (Report of the Geological Survey of Ohio, 1870, p. 277, and 1873, p. 129).

The lithological characters of the Guelph limestones, wherever they may occur, are very constant. The characteristic rock of the formation is a rough, cellular, yellowish or creamy dolomite, of a rough texture and crystalline appearance, exhibiting innumerable cavities, from which fossils of various kinds have been dissolved out. The organic remains which at one time existed in the rock must have been extremely numerous; but they are so preserved as rarely to show any of the finer details of structure, and in the majority of instances they present themselves only in the form of casts or moulds. Amongst the characteristic fossils of the Guelph formation, in all or most of the localities in which it has yet been detected, may be mentioned *Pentamerus occidentalis*, Hall, various species belonging to the Trimerellidæ, *Megalomus canadensis*, Hall, corals belonging chiefly to *Favosites* and *Amplexus*, and a numerous assemblage of Gasteropods belonging chiefly to the genera *Murchisonia*, *Pleurotomaria*, *Subulites*, and *Holopea*. In some localities the formation has also yielded a large number of Crinoids and Cystideans; but these are hardly or not at all represented in the formation as seen in Canada. Similarly, Polyzoa, though very abundant in some localities, appear to be entirely wanting in others, even over large areas.

In the present communication I propose to make some observations on the *Gasteropoda* of the Guelph formation of Canada, so far as these are known to me. The Gasteropoda constitute perhaps the most abundant and characteristic fossils of the Guelph formation; but they are generally very badly preserved, occurring almost exclusively in the form of casts or moulds, from which the actual substance of the shell has usually been entirely removed. They have been described by Professor Hall (Pal. N. Y. vol. ii. pp. 345–349; Geol. Survey of Wisconsin, 1861, pp. 34-36; and Twentieth Report on the State Cabinet, pp. 341–347 and 364–367) and by Mr. Billings (Palæozoic Fossils, pp. 154–160 and p. 169); but much remains to be done, owing to their poor state of preservation, before we shall be fully acquainted with their characters. This is the more to be regretted, as most of the species appear to be peculiar to the formation, and have not been satisfactorily identified with similar forms in older or younger deposits.

MURCHISONIA LOGANII, Hall. Plate XXVI. figs 3, 4.

M. Loganii, Hall, Pal. N. Y. vol. ii. p. 346, pl. lxxxiii. figs. 4 *a*, *b*.

Spire elongated, of numerous whorls (eight to twelve), apical angle about 15°. Whorls strongly convex, smooth and rounded in the cast, but exhibiting, in well-preserved specimens in which the shell is retained, a distinct but low band, placed about the centre of each whorl. Body-whorl not ventricose. Columella large, not marked with a spiral fold. Suture deep. Surface apparently smooth and without striæ.

This species is one of the commonest and most characteristic of the *Murchisoniæ* of the Guelph formation; but it is usually badly preserved, and its full characters are not yet known. In an ordinary way, fragments may be recognized by the rounded, convex whorls, which do not very rapidly increase in size, and are not very oblique. Views of the interior are often obtained, and are very characteristic, the columella being simply rounded and not folded as in *M. bivittata*, whilst it is far less thick than in *M. longispira*. The body-whorl is only slightly larger than the next whorl; and I have seen no specimen exhibiting the aperture. According to Hall, however, the last volution expands towards the aperture, and there is an expanded umbilicus. Casts of the shell are smooth; but examples in which portions of the shell are preserved show that there was a flat spiral band running along the centre of each whorl, the convexity of the whorl being equal above and below the band.

The size of the shell in *M. Loganii* seems to have been variable; but none of my specimens is quite perfect. The largest specimen in my possession (fig. 3) is a fragment, broken at the top, consisting of six whorls, having a length of two and a half inches, the width of the body-whorl being eleven lines, and the width at the summit being five lines. Other examples, however, do not appear to have reached these dimensions.

Formation and Locality. Guelph Limestones; Elora, Guelph, Hespeler, Western Ontario. Also in rocks of the same age at Racine, Wisconsin, and Leclaire, Iowa (Hall).

MURCHISONIA TURRITIFORMIS, Hall. Plate XXVI. fig. 10.

M. turritiformis, Hall, Pal. N. Y. vol. ii. p. 347, pl. lxxxiii, figs. 6 *a. b.*

Spire long, turreted, many-whorled. Apical angle about 12°. Whorls increasing very slowly in size, their outer surfaces very slightly convex or nearly flat, so that the two sides of the shell are nearly parallel about its middle. Suture not deep. Well-preserved specimens show a distinct spiral band a little below their centre. Surface and aperture unknown.

Nothing but fragments of this species have ever been described; and all the specimens in my possession are imperfect. The shell must have attained a considerable size, and probably possessed not less than twelve or fifteen volutions. The species is nearly allied to *M. Loganii*, Hall, from which it is distinguished by the much flatter whorls and less deeply excavated suture. I have seen no examples showing the interior; but Hall states that the columella is of small size. The body-whorl does not appear to have been ventricose; and such specimens as show portions of the actual shell would lead to the belief that the surface was smooth. The carina, though not strongly elevated, is generally easily recognized, and is usually placed decidedly below the centre of the whorls.

Formation and Locality. Guelph Limestones; Elora, Guelph, Galt, &c., Western Ontario.

MURCHISONIA MACROSPIRA, Hall. Plate XXVI. fig. 9.

M. macrospira, Hall, Pal. N. Y. vol ii. p. 346, pl. lxxxiii. fig. 5.

"The specimen consists of the mould, showing the impression of four and part of the fifth volution, marked by a strong carina along the centre; last volution showing a large canal extending downwards in the direction of the spire. This species is larger and stronger than the preceding" (*i. e. M. Loganii*). Hall, *loc. cit.*

I am not aware that any other description than the above has ever been published of *M. macrospira*, though the species is often quoted. Prof. Hall's description, however, is taken from a single imperfect example, and it is not sufficiently full to render identification easy. The only specimen in my collection which I should be disposed to regard as belonging to *M. macrospira* is a large fragment about three inches in length, an inch and a half wide at the broken base, and half an inch wide at the broken summit. The specimen exhibits six whorls, the greater portion being hollow and exhibiting the interior of the shell, whilst the remainder is occupied by the cast. The apical angle is about 20°; and the whorls rapidly increase in size from above downwards. The columella is remarkably thick and strong, but is simply rounded. The existence of a carina cannot be determined; and the specimen gives no information as to the characters of the surface or the nature of body-whorl and aperture.

If the above specimen be rightly identified with *M. macrospira*, Hall, then the species is nearly allied *M. Loganii*, from which it differs in its larger dimensions, and proportionally more rapid rate of expansion. Judging from the figure given by Hall, the carina, also, would appear to be very broad and flat, which is not the case in *M. Loganii*. Better specimens would doubtless show that the two species are separated by other characters.

Formation and Locality. Guelph Limestone; Elora, Western Ontario. It has also been quoted from the same formation in Ohio.

MURCHISONIA BIVITTATA, Hall. Plate XXVI. fig. 7.

M. bivittata, Hall, Pal. N. Y. vol. ii. p. 345, pl. lxxxiii. figs. 1 *a*, *b*.

In the condition of preservation in which the specimens in the Guelph dolomites occur, this species can only be recognized, with any certainty, in examples which exhibit the interior of the shell. In these we find the characteristic peculiarity that the columella is marked with a conspicuous double spiral fold, the obliquity of which varies in different specimens. So far as can be judged, such specimens, all of which are fragmentary, appear to expand with moderate rapidity, and to have an apical angle of about 15°, the number of whorls being unknown, but stated by Hall as more than twelve.

Specimens exhibiting the exterior, but not showing the columella, cannot, in the present state of our knowledge, be certainly referred to *M. bivittata*. One small example (fig. 8), which, from its general form and proportions, I should be disposed to refer to this species, is about twenty lines long, and consists of about six whorls. The apical angle is about 18°; and the whorls are carinated about their middle, being convex below the carina and slightly concave above it. The body-whorl is expanded towards the aperture. I cannot, however, affirm with any certainty that this is really a young individual of *M. bivittata*.

Formation and Locality. Guelph Limestones; Elora and Hespeler, Western Ontario.

MURCHISONIA (?) LONGISPIRA, Hall. Plate XXVI. figs. 11, 12.

M. longispira, Hall, Pal. N. Y. vol. ii. p. 345, pl. lxxxiii. figs. 2 *a*, *b*.

Spire long, turreted, composed of numerous volutions. The whorls increase very slowly in size in proceeding from the apex to the base. Apical angle about 10° or less. Whorls rounded externally, with a carina below the centre (Hall). Columella remarkably thick, rounded, without being in any way twisted or folded.

This species may be recognized by its slender elongated spire and numerous volutions. None of my specimens are perfect, the largest being a fragment ten lines long, two and a half lines wide at the broken base, and rather more than one line in width at the broken summit. The most conspicuous character of longitudinal sections is the great thickness of the simply rounded columella, which occupies nearly one half of the total thickness of the whorls.

Professor Hall apparently regards this species as being a *Loxonema*; but I do not know upon what grounds he has changed his original determination, and none of my specimens shows the surface.

Formation and Locality. Guelph Limestones; Elora, Western Ontario.

Murchisonia Boylei, Nicholson. Plate XXVI. fig. 1.

Shell turreted, with a long conical spire. Apical angle 18°. Whorls ten or eleven in number, increasing regularly in proceeding from the apex to the base, flat, with a well-marked spiral band or angulation just above the suture. Suture apparently canaliculated. Body-whorl not ventricose. Base somewhat produced below, apparently with a small umbilicus. Length of the only individual observed two and a half inches, width of body-whorl eleven lines.

This species is distinguished from *M. turritiformis*, Hall, *M. Estella*, Billings, and *M. longispira*, Hall, by its more rapid rate of expansion. It is further distinguished by its apparently canaliculated suture, and the existence of an angular band a little above the suture, causing the lower portion of each whorl to project considerably above the upper portion of the whorl next below. Above the band the whorls are quite flat.

The above description is taken from a fine gutta-percha cast, which exhibits all the essential characters except the mouth. The original specimen was discovered by Mr. David Boyle, Head master of the Public School of Elora, Canada, and is now in the Museum of the University of Toronto.

Formation and Locality. Guelph Limestones; Elora, Ontario.

Murchisonia Vitellia, Billings. Plate XXVI. fig. 6.

M. Vitellia, Billings, Palæozoic fossils of Canada, p. 156, fig. 138.

Shell with an elevated and conical spire of about four angular volutions. Apical angle rather more than 50°. Body-whorl strongly ventricose, and, in common with all the other whorls, furnished with a broad and flat spiral band along the middle, giving rise to an obtuse angulation. Whorls convex below the band; and flat or slightly concave above it, except the upper whorls, which there are somewhat convex. The band is slightly concave; and the surface exhibits fine striæ, with indications of stronger rugæ, which curve backwards above the band and forwards below it.

In the best-preserved specimen in my collection, the length of the shell, when perfect, must have been somewhat over two inches, of which the body-whorl occupies one inch. The width of the body-whorl is an inch and a half.

M. Vitellia is readily distinguished from the other *Murchisoniæ* of the Guelph formation by the general form of the shell, the angular volutions, the broad flat or slightly concave band, and the great size of the body-whorl. The aperture is unknown; but the base appears to have been rounded, and a small umbilicus seems to have been present.

Formation and Locality. Guelph Limestones; Elora, Ontario.

Murchisonia Hercynia, Billings. Plate XXVI. fig. 2.

M. Hercynia, Billings, Palæozoic Fossils, vol. i. p. 158, fig. 141.

Shell conical or trochoid, with a nearly flat base. Apical angle about 65°. Whorls five or six, gently rounded, with a moderately deep suture. The outer edge of the body-whorl is narrowly rounded; but there are no distinct indications of a carina on this or on any other of the volutions. Surface covered with fine lamellose striæ, which curve obliquely backwards from the suture to the lower edge of the whorl. Length of the shell fourteen lines, width at the base one inch.

I should be inclined to doubt if this shell can be with any certainty referred to *Murchisonia*; but there can be no question as to its specific distinctness. It has not only been recognized by Mr. Billings and myself in the Guelph formation of Canada, but has been detected by Hall in strata of the same age at Racine, Wisconsin (Twentieth Report on the State Cabinet, p. 345).

Formation and Locality. Guelph Limestones; Elora, Ontario.

MURCHISONIA, sp.

Shell conical, turreted, with a long spire. Whorls robust, rapidly expanding, flat, the lower portion of each projecting beyond the upper part of the whorl immediately below. There are obscure indications of a band placed a little above the suture. Length of an imperfect specimen two inches, width of the base fourteen lines.

This form somewhat resembles *M. Boylei* in its general characters, but is altogether much larger. The materials in my hands, however, are not sufficient to permit of its satisfactory determination.

Formation and Locality. Guelph Limestones; Elora, Ontario.

CYCLONEMA (?) ELEVATA, Hall. Plate XXVI. figs. 16, 16 *a*.

C.? elevata, Hall, Twentieth Report on the State Cabinet, p. 342, plate xv. fig. 4.

Shell conical, with an elevated spire. Apical angle from 35° to 40°. Whorls five in number, convex, with a deep suture, gradually enlarging to the aperture. Body-whorl not ventricose. Aperture broadly ovate. Surface unknown.

The best-preserved specimen in my possession has a height of thirteen lines, the width of the base being ten lines. The height of the aperture is six lines, the width of the same being five lines.

The specimens in my collection, though in all respects slightly larger, so closely resemble the shell figured and described by Hall under the name of *Cyclonema? elevata*, that I do not feel justified in separating them. One of my examples, however, exhibits distinct indications of an obscure and shallow band about the centre of the body-whorl, which is not the case in the specimens described by Hall. The surface is stated by Hall to possess evidence of revolving striæ; but I cannot bring forward any evidence on this head. My specimens are all in the condition of casts, and exhibit a distinct but small umbilicus. Upon the whole, I should be disposed to think that the present form is probably referable to *Holopea*, presenting considerable affinities with *H. guelphensis*, Billings.

Formation and Locality. Guelph Limestones; Elora, Ontario.

HOLOPEA GUELPHENSIS, Billings. Plate XXVI. fig. 18.

H. Guelphensis, Billings, Palæozoic Fossils of Canada, vol. p. 159, fig. 143.

Shell conical, with an elevated spire. Apical angle about 80°. Whorls three, convex, the body-whorl large, but not excessively ventricose. Aperture broadly ovate; umbilicus small. Surface unknown.

Length about one inch; width of base rather less (according to Mr. Billings, 9 lines). Height of aperture six lines; width of aperture five lines.

I can add little or nothing to the description of this species given by Mr. Billings—since I have never seen any thing but casts, and the best-preserved specimen in my possession is distorted. *H. guelphensis,* though allied to *Cyclonema? elevata,* Hall, is clearly distinct from it, the spire of the latter being much more slender and elevated, and the apical angle being very much less.

Formation and Locality. Guelph Limestones; Elora, Ontario. The same species has been recognized by Hall in the limestones of Racine, Wisconsin.

HOLOPEA GRACIA, Billings. Plate XXVI. fig. 17.

H. Gracia, Billings, Palæozoic Fossils of Canada, vol. i. p. 159.

Shell conical, with a slightly elevated spire. Apical angle 90° or rather more. Whorls four, convex, uniformly ventricose. Body-whorl not much expanded. Aperture apparently rounded. A small umbilicus. Surface unknown.

According to Mr. Billings, the width is twelve lines, and the length thirteen lines. In the only specimen in my possession the spire is imperfect, and the width is fifteen lines, whilst the length is twelve lines.

H. Gracia is closely allied to *H. guelphensis*; but the spire is more depressed, the apical angle is considerably greater, and the body-whorl is proportionally not so large.

Formation and Locality. Guelph formation; Elora, Ontario.

SUBULITES VENTRICOSUS, Hall. Plate XXVI. fig. 5.

S. ventricosa, Hall, Pal. N. Y. vol. ii. p. 347, pl. lxxxiii. figs. 7 *a*, *b*.

Shell subulate, with an elongated spire. Volutions four to six, convex; the body-whorl ventricose, produced anteriorly, equalling or exceeding in length the remaining whorls put together. Apical angle about 16°. Surface and aperture unknown.

The dimensions of a small individual are:—length fifteen lines, of which the body-whorl occupies rather more than eight lines; width of body-whorl five lines.

My specimens are so poorly preserved that I can add little to the meagre descriptions of this species which have been already published. The general form of the shell would seem to justify its reference, at any rate provisionally, to the genus *Subulites.*

Formation and Locality. Guelph Limestones; Hespeler, Ontario.

PLEUROTOMARIA SOLARIOIDES, Hall. Plate XXVI. fig. 15.

P. solarioides, Hall, Pal. N. Y. vol. ii. p. 348, plate lxxxiv. figs. 4 *a*, *b*.

Shell depressed, of four or five volutions, which are convex externally. Umbilicus very large, exposing the whorls to the apex (in the cast). The base is nearly circular, and has a diameter of ten lines in an average individual. The whorls are flattened from above downwards; and the body-whorl is not expanded. Surface and aperture unknown.

I do not feel at all sure as to the true position of the specimens which I have referred here. They occur wholly in the condition of casts; and though I have no doubt as to their identity with the examples described by Hall under the above name, their generic affinities seem very doubtful. They exhibit no evidence of a carina, and are just as likely to belong to *Straparollus* as to *Pleurotomaria*.

Formation and Locality. Guelph Limestones; Elora and Hespeler, Ontario.

PLEUROTOMARIA, sp. Plate XXVI. figs. 13, 14.

Shell conical, with an elevated spire. Whorls four, narrowly rounded below, but nearly flat for their upper two thirds (in the cast). Suture deep. Body-whorl expanded moderately towards the aperture. Base somewhat flattened, showing in the cast a small umbilicus. Surface unknown. Aperture apparently rounded.

Length of a large specimen seven lines, width of the base six lines. In a small specimen, the length is five lines, and the width of the base is four and a half lines.

In some respects, this form resembles *Pleurotomaria elora*, and *P. galtensis*, Billings, though very clearly distinct. Indeed it may be doubted whether it belongs to *Pleurotomaria* or whether it may not rather be referable to *Holopea*. I cannot identify it with any previously recorded form; but my specimens are all in the condition of casts, and I prefer to leave its specific position an open question.

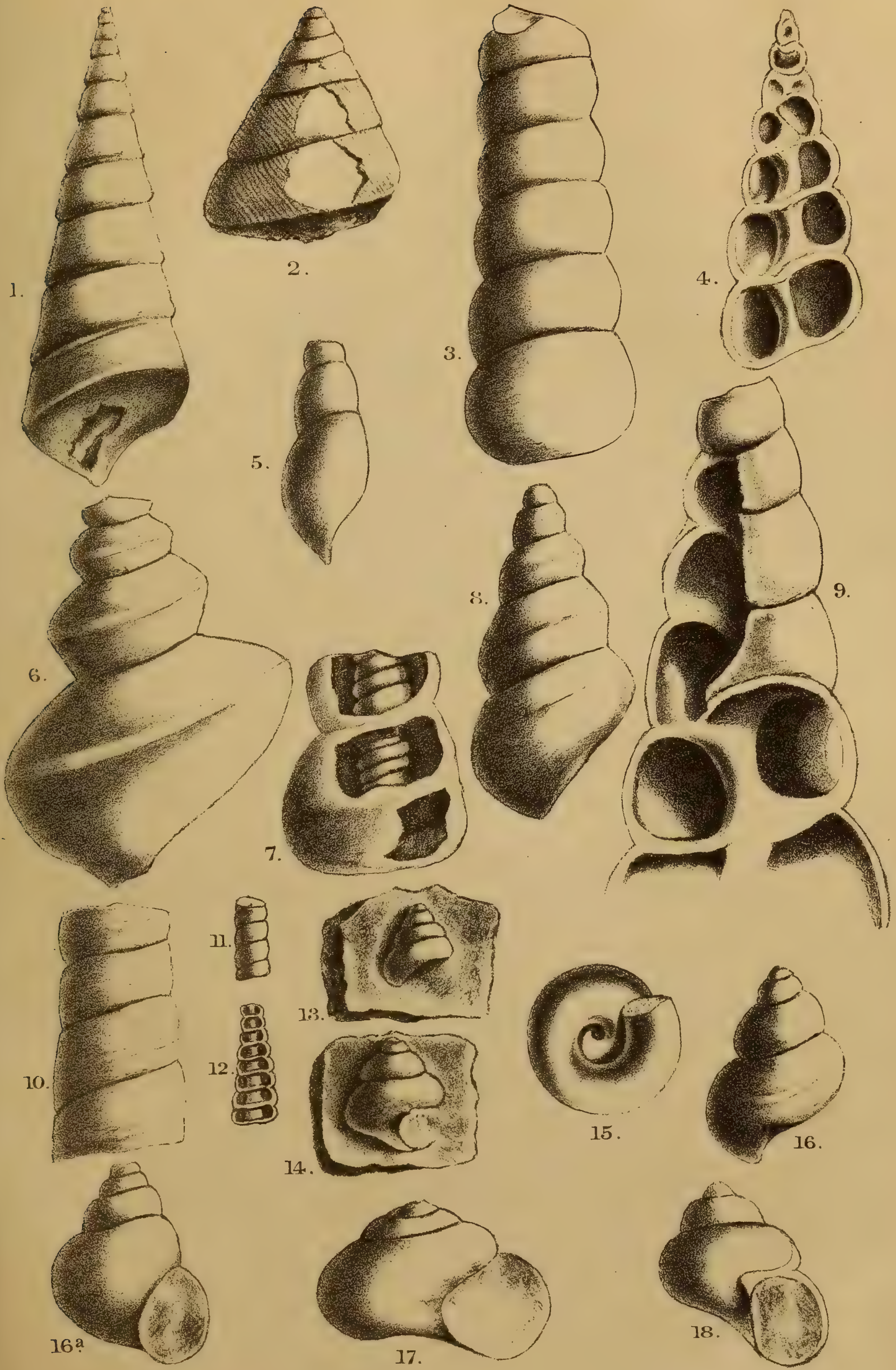
Formation and Locality. Guelph Limestones; Elora, Ontario.

HOLOPEA (?) OCCIDENTALIS, Nicholson. Woodcut, p. 551.

Shell conical, with a small but elevated spire. Whorls five, convex, with the greatest convexity in the upper fourth. Body-whorl extremely large, occupying nearly three fourths of the length of the shell. The body-whorl is moderately expanded towards the aperture, at which point it is almost free. Aperture circular. In the cast there is a large umbilicus.

The length of the shell is twenty-one lines; the width of the base (including the aperture) is nineteen lines; the height of the body-whorl is fifteen lines; the height and width of the aperture are both nearly nine lines; the width of the umbilicus is four lines; and the height of the spire is about six lines. Surface-characters unknown.

It is impossible to feel certain whether this form is rightly referable to *Holopea* or not, though its general form would lead us to place it



H. A. Nicholson del et lith.
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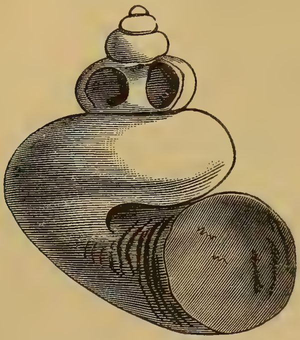
GUELPH GASTEROPODA.

in that genus. The species is distinguished by its short but elevated spire, its large body-whorl, becoming almost disjunct at the aperture, its circular aperture, and large umbilicus. The upper whorls are almost uniformly convex; but the body-whorl is obtusely angulated at about its upper fourth, being somewhat flat from this point to the suture. The suture is deep. There are no traces of a band or carina.

Fig. *Holopea occidentalis,* Nich.



Formation and Locality. Guelph Limestones; Elora, Ontario.

EXPLANATION OF PLATE XXVI.

Fig. 1. *Murchisonia Boylei,* Nich., of the natural size.
2. *Murchisonia Hercynia,* Billings, nat. size.
3. Fragment of large specimen of *Murchisonia Loganii,* Hall, of the natural size.
4. Longitudinal section of another example of the same, showing the form of the columella; nat. size.
5. A small example of *Subulites ventricosus,* Hall, nat. size.
6. A large, but imperfect example of *Murchisonia Vitellia,* Billings, nat. size.
7. *Murchisonia bivittata,* Hall: two whorls exhibiting the form of the columella, of the natural size.
8. A small example (cast) probably referable to *Murchisonia bivittata*; nat. size.
9. A large but imperfect example of *Murchisonia macrospira,* Hall (?), partly showing the interior; nat. size.
10. Fragment of *Murchisonia turritiformis,* Hall; nat. size.
11. Fragment of the cast of *Murchisonia longispira,* Hall; nat. size.
12. Longitudinal section of another example of the same, showing the form of the columella; nat. size.
13, 14. An undetermined species of *Pleurotomaria,* nat. size.
15. Under surface of *Pleurotomaria solarioides,* Hall, nat. size.
16. 16*a*. *Cyclonema* (?) *elevata,* Hall, nat. size.
17. Cast of *Holopea Gracia,* Billings, nat. size.
18. Cast of *Holopea guelphensis,* Billings, distorted by pressure; nat. size.

41. *The* Physical Conditions *under which the* Cambrian *and* Lower Silurian Rocks *were probably deposited over the* European Area. By Henry Hicks, Esq., F.G.S. (Read June 23, 1875.)

[Plate XXVII.]

Wherever the base-line of the Cambrian rocks is seen throughout the European area, it is found invariably to rest unconformably upon an earlier series of rocks, which are supposed to be of the age of the Laurentian rocks in Canada. These præ-Cambrian rocks in Europe therefore, like the Laurentian rocks in America, indicate that large continental areas existed previous to the deposition of the Cambrian rocks. The European continent seems to have occupied at that time a larger area than at present, and to have extended in a continuous line from above Norway and Lapland to the south coast of the Mediterranean, portions of this continent being now apparently visible in Algiers and to the south of the Black Sea. In an east-and-west line it would extend from at least the 100-fathom line beyond the British Isles, to Asia. The higher land would be towards the north-east; and the trend of the land would be in a direction towards the south-west, a difference of level of probably 15,000 feet occurring between the higher lands to the east and the low lands in the west. The surface of this continent seems to have been more or less of an undulating character, with the higher ranges running in the direction of east-north-east and west-south-west. The strike of the immediately overlying beds usually takes this course also; and the now exposed portions of the old continent, which then formed the higher points of the ranges, show also a long axis in that direction. When therefore this continent began to subside, the part facing the south-west became first covered over by the sea; and the direction in which the sea encroached is now evident by a consideration of the order of the deposits as they were thrown down, and of the successive faunas which became entombed. We have no knowledge of how far the continent extended to the south-west, nor of the thickness of deposits which may have taken place over such areas if they existed; therefore for present purposes we must consider the depression from the time only that the record is preserved to us. The land which was lowest and facing the Atlantic ocean, which doubtless then, as now, formed one of the great oceanic basins, would become first submerged and would receive deposits, whilst the higher portions would still remain above water. The evidence derived from the consideration of the deposits shows also that the depression of the præ-Cambrian land was very gradual, and on the whole regular, and that the portions the furthest to the north-east were the last to become submerged. In England the Cambrian and Lower Silurian deposits attain to a thickness of from 25,000 to 30,000 feet, exclusive of interbedded tuffs or contemporaneous traps, whilst in Sweden the deposits representative of these epochs do not attain to more than, at the most, 1000 feet. In Russia they are still of less thickness; and there the earlier deposits seem to be entirely absent. In Bohemia they seem to occupy an almost intermediate position, as to thickness and order of deposition, between those of Britain and those of the extreme north; and this is what might naturally be expected if my suppositions are correct. However, to prove these facts it is necessary to examine the series carefully in each area both by palæontological and stratigraphical evidence. On the chart (Plate XXVII.) the order and thickness of the deposits in each area are shown, and the character of the sediment indicated.

Taking the British Isles first, and making the Welsh sections to represent the general order over the areas to the south-west, we find (1) at the base of the series beds of conglomerates consisting of quartzy pebbles and other masses which are undoubtedly identical in character with the rocks composing the underlying ridges of præ-Cambrian rocks, and indicating beach-conditions. Following these (2) are sandstone beds ripple-marked, or shallow-water accumulations; (3) finer beds are thrown down, indicating that a somewhat greater depression had rather suddenly taken place, and the earliest organisms known in this region are here entombed, having been evidently driven in from the deeper water to the south-west, where probably they had attained through successive changes the stage of development then shown; (4) the depression was very gradual for a long period, and the beds were deposited in shallow water, being for the most part sandstones; (5) a more sudden depression takes place and finer beds are thrown down, in which our second fauna occurs; (6) another quiet and gradually subsiding period, which, however, is followed by (7) a very decided depression, in which our third fauna occurs. This depression, which may be called the "Menevian," and which, taking the whole epoch, caused alone a change of level of probably over 1000 feet, when added to the 8000 or 10,000 feet which had already taken place, allowed the waters to spread freely over the areas extending between the south of Prussia and Bohemia, and Norway and Sweden. There is no evidence of the presence of our first and second faunas in any of the regions so far to the north and east, the lowest beds in Norway and Sweden being probably equivalent only to our Menevian group; and the evidence is strong also that the first Bohemian fauna was the passage onwards of our third or early Menevian fauna, and that the waters did not reach the so-called Bohemian basin until most, if not the whole, of our Longmynd group had been deposited. This depression was not sufficient, however, to allow the waters to spread over the Russian areas; therefore we have no rocks of this age there. Coming back again to our British areas, we find that our last depression has been very gradually filled up, and shallow-water accumulations are again deposited. During the next, or Lingula-flag period, shallow-water accumulations were almost universally thrown down; and though they include over four thousand feet of beds, and consequently indicate a depression to that extent, yet in no case do we find, until we come towards the close of the epoch, the depression occurring at a greater rate than would keep pace with the accumulations. This is partly due to the slow and regular depression, and partly to the increased area exposed to the action of the waves by the spreading of the water during the Menevian epoch. Doubtless also much loose material was washed down from the continents as they were depressed; and this was being continually carried out from the shores and spread over the accumulations, so filling up areas which otherwise would have been covered by deeper water. The next rather sudden depression was that which took place at the commencement of the Tremadoc epoch; and it was at this period that the western and southern parts of Russia became submerged; for we do not find any beds there of older date than our Arenig or Llandeilo, and these seem to rest directly on the old præ-Cambrian land. During the depression, which extended over the Tremadoc, Arenig, and Llandeilo periods, moderately deep water covered the western areas; and the accumulations are consequently of a fine muddy character, unless when under the influence of tidal currents, or, as at the close of the Arenig, of volcanic disturbances. The land at this time under the immediate influence of wave-action was far removed from these areas; and the deposits therefore were heaped up more slowly, as may be seen in the fine slaty beds in France and England. In Wales, a region much disturbed afterwards by volcanic agencies, at least 4000 feet of these fine muddy deposits were thrown down before the commencement of volcanic action in that region; and these were formed independently of volcanic products.

In Russia, in consequence of being near the wave-action and the remaining continental area, which probably did not become submerged in parts of Asia until the Devonian epoch, gritty beds were thrown down at this time.

At the close of the Lower Silurian the sea-bottom was possibly in in some parts raised above sea-level; but it is evident that in most areas it remained still submerged. The elevation seems to have been chiefly along the line of volcanic action, and was doubtless assisted by movements in the earth's crust, as well as by the spreading of ashes and lavas over the sea-bottom. The volcanoes at first were submarine; and though in some cases they afterwards seem to have heaped up sufficient material to rise above the surface of the water, yet they all became submerged again before the close of the epoch, and conformable sediments are seen to cover them over. The stratigraphical evidence therefore strongly favours the view that a gradual depression took place during the whole of the Cambrian and Lower Silurian epochs over the European area, and that the deposits form one complete and natural succession from the base upwards. The evidence derived from a consideration of the faunas is entirely in accordance with this view. In no case do we find any forms but those which must have been marine; not a single freshwater fossil has yet been found. The first fauna of which we have any knowledge occurs in the beds furthest to the west, and there in earlier beds than any which occur in the regions more to the east; and though the forms which make up this fauna belong to inferior classes, yet they are not the lowest types in those classes, but often show evidences of considerable progression in development. On this account I have often expressed the opinion that we were far from the beginning of this type of life even in the earliest Cambrian faunas, and that the forms had already undergone many changes previous to this period. It is easy now to see how these changes could have taken place, and moreover how it was that new forms so frequently appeared at certain stages highly developed and with no previous evidence in the rocks as to the changes they had undergone. The home of the earliest forms of life seems to have been somewhere towards the south-west, and possibly not far from the equator; and it is from here that the various forms seem to have migrated to the areas in which they were subsequently entombed. The migrations seem to have taken place towards the North-American continent very much about the same time as towards the European; and the sea-encroachments along that continent seem to have been in a direction from south-east to north-west, so that the lines indicating the two depressions would meet in mid-Atlantic. This accounts for the great similarity in the two faunas, and for the general resemblance offered by the order of succession of these early rocks in the two continents. The higher lands in America would be to the west and north-west, and the higher lands in Europe to the east and north-east; so that the last lands submerged would approach each other and occupy the same region of the globe. This land would doubtless be clothed with plants before it was submerged; but subsequent marine denudation would remove all traces of vegetation. The plant-remains preserved in the Upper Silurian and Devonian are indications of the general character and the state of progression of the vegetation at that time. In the Cambrian rocks the evidence of land vegetation is imperfect, though I am of the opinion that some markings now visible on these rocks were produced by land plants which were then washed from the præ-Cambrian lands as the waters encroached upon them. It is impossible in any other way to account for the rich vegetation of the Carboniferous period or for the progression which had then taken place in vegetation. The conditions which would allow the waters to teem with life in earlier periods, would also enable progression to take place in animal and vegetable life on the land. When, therefore, the European continent again appeared above the water, which took place by the levelling of a large surface of the globe through the combined action of denudation and the heaping up of material, aided in some cases by upward movements in the earth's crust, the vegetation spread rapidly, and enormous areas were soon covered with forests, and tenanted by air-breathing invertebrates and vertebrates, which migrated thither from regions not then reached by the water.

If I am correct in my suppositions that the sea encroached from the west, that the first faunas were brought in from that direction, and that the subsequent faunas in these areas also migrated along the same line, then, especially if it is true that the whole of the Cambrian and Lower Silurian rocks form a truly conformable series, and that they were deposited regularly over a gradually subsiding area, we evidently ought to find some evidence here to prove the truth or fallacy of the evolution theory as to the beginning of life and subsequent development. The picture offered to my mind in the consideration of these early forms of life is one most strongly in favour of such views; and the evidence seems both clear and convincing. Taking the three earliest faunas together, which are all in the Lower Cambrian rocks, we find the following seven great groups present:—Annelides, Brachiopods, Trilobites, Ostracods, Cystids, Sponges, and Pteropods. With regard to the first five, if we are to believe biologists such as Fritz Müller, Häckel, and others, the evidence is most strong, not only that they are very nearly allied, but also that they could easily, and without undergoing any very great changes, have been derived from one common form. Of the other two the Sponges are of so inferior a grade that they may probably have dated back to the time of the *Eozoon*, whilst the Pteropods found are so simple in their structure that we may look upon them as being early offshoots from which may subsequently have been developed the Cephalopods and Gasteropods. These early forms tenanted the seas when the Laurentian continents alone existed, and before even a bed of our Cambrian rocks, as now exposed to us, was deposited; and if there were no other higher forms in more favoured spots, and nearer to the original home, these are ample to show that a long period must even then have been passed over before this progress could have taken place. It does not appear in any way necessary that these were the highest forms in existence at this time; and, indeed, it seems more reasonable to think that they were not, and that higher forms were even then ready to migrate, if not already on their way; for when the seas along these areas are again sufficiently deep for an easy passage forward, a much higher fauna appears, and the higher invertebrates, the Cephalopods, Gasteropods, and Lamellibranchs, are found along with the groups which had appeared in the earlier faunas. It is an interesting fact and one which tends to show the line of migration, that these again appear in the western (or Welsh and Spanish) areas at a much earlier period than in the eastern. The time which must have elapsed, according to present evidence, between the appearance of the lower invertebrate fauna in the Longmynd Group and of the higher fauna in the Tremadoc Group must have been great, as it means the deposition of at least from 8000 to 10,000 feet of beds; and though this may not have been sufficient to allow for all the changes in the forms, yet it was quite sufficient for the migration to have taken place even at a slow rate.

There is much other and additional evidence of this nature to be found by the examination of these early faunas. The western areas have a larger number of orders, a greater number of genera, and in the genera show a greater number of varieties or stages of progression than we find in any of the more eastern areas. Many of these steps or species are wanting in the eastern areas; and it is probable that they never reached so far, just as it is evident that many intermediate forms did not reach the western areas. Many forms, as they fulfilled their mission, were lost on the way; and it is only the stronger and more marked varieties, which we now look upon as species, that were able to pass on. Minor changes may also have taken place even in very limited areas; but it is evident that the more marked species were tolerably persistent and became more generally distributed.

The conclusions to be drawn from the foregoing remarks are these:—

1. That a præ-Cambrian continent extended over all the area now known as Europe, and that it probably reached considerably further to the west and north than it does at present, that this continent had a general inclination towards the south-west, and that there was a difference of level of at least 15,000 feet between the extreme north-east and the south-west.

2. That the submergence of this continent was gradual, and that the waters encroached from the south-west.

3. That the eastern portions of the continent did not become submerged until after the whole of the Cambrian (Longmynd, Menevian, Lingula-flag and Tremadoc groups) had been deposited over the western areas, and that dry land continued probably to the beginning of the Devonian epoch in the more extreme eastern frontiers, in Asia.

4. That the migrations of the marine faunas were from the south-west, where oceanic areas prevailed.

5. That the earliest faunas which reached the European continents indicated a lower type of organic life than those which succeeded them, and that each successive fauna seemed to indicate a higher state of progression, the lowest invertebrates appearing first, and the higher groups not until several preceding faunas had appeared, —this being more marked in the western than in the eastern areas, as many forms had probably ceased to exist by the time the waters had reached the eastern areas.

EXPLANATION OF PLATE XXVII.

Outline map of Europe, showing the comparative thickness and depth of deposition of the Cambrian and Lower Silurian rocks in different areas. The comparative depth of water in which the deposits were probably formed is indicated by the depth of tint in the sections.

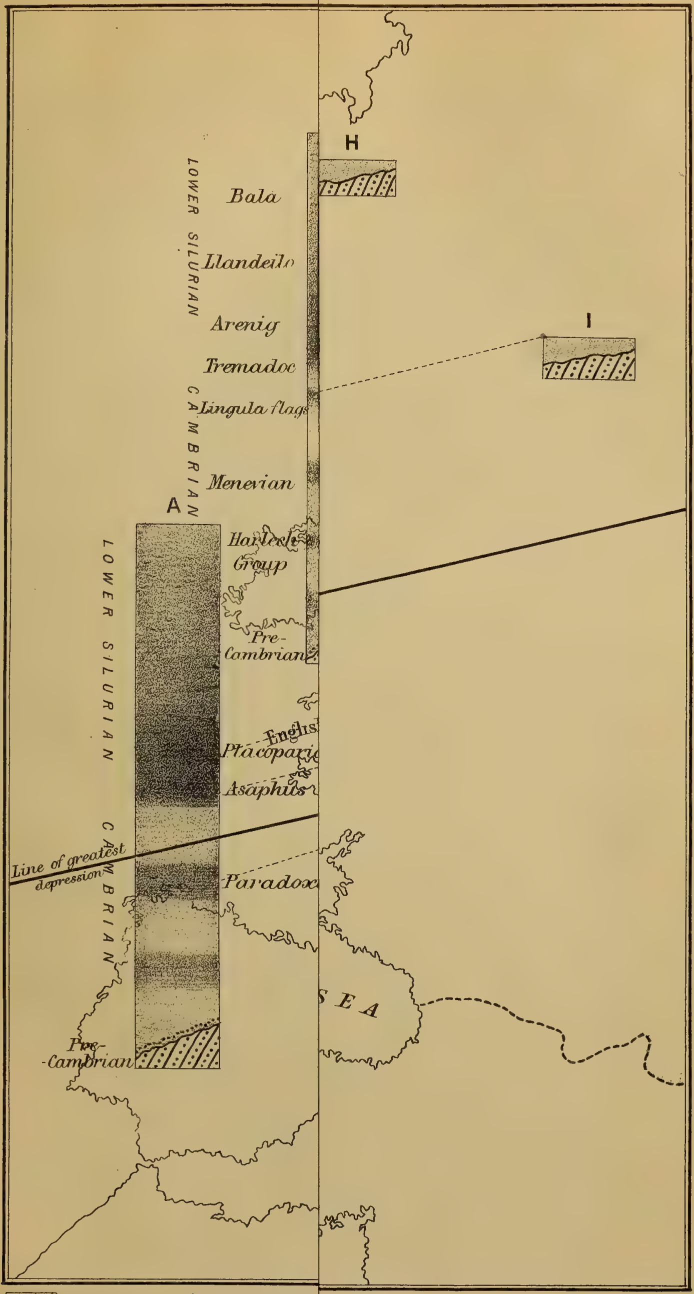
Section A. Central regions of Spain (Guadarrama, Montes de Toledo, Province of Leon, Daroca, &c.).
" B. Wales, North and South. For the most part this also represents the succession in France (Brittany &c.).
" C. Sardinia. The succession here has not yet been thoroughly worked out; but this section appears to represent generally the conditions observed here and also on the south coast of the Mediterranean (Algiers &c.).
" D. Bohemia and Bavaria.
" E. Norway and Sweden (neighbourhood of Christiania, Lake Wenner, &c.).
" F. West coast of Russia (Finland and neighbourhood of St. Petersburg).
" G. Podolia.
" H. Shore of the Arctic Sea (region of Petschora &c.).
" I. Ural Mountains.

Discussion.

Prof. Ramsay stated that he agreed with much of what Mr. Hicks had said, but doubted whether he was justified in speaking of all the metamorphic rocks referred to as Præ-Cambrian, seeing that in Europe we have metamorphic rocks in all formations, even up to the Eocene. He thought the greater part of the Cambrian and Lower Silurian rocks were deposited in shallow, and perhaps to some extent in fresh water; the series includes many volcanic rocks of a kind which could not have been thrown up under great sea-depths. Volcanic rocks occur in the Arenig, Llandeilo, and Bala groups, which indeed are chiefly made up of stratified volcanic products. In Cumberland the series consists of volcanic ashes, lavas, &c., with no ordinary sedimentary deposits; and when the contortions of the strata took place the volcanic ashes were converted into slates. The whole of these were derived from terrestrial volcanoes; and the same thing had partly happened in Wales. Prof. Ramsay thought it was a great mistake to speak of all these as deep-water deposits.

Mr. Hicks, in reply, stated that where the rocks which he had mentioned as belonging to the old præ-Cambrian continent were now found exposed they showed every indication of having been old land surfaces before the overlying rocks had been deposited; and almost invariably the lowest beds in contact with them were either sandstones or conglomerates, whether they belonged to the Cambrian or the Silurian. He even believed that we should find that in Asia Devonian rocks would be found to lie directly on the frontier of this old Laurentian land, which here had remained above the surface during the whole period of the formation of the Cambrian and Silurian rocks in other areas. He believed that land vegetation had gradually attained perfection during these periods on this old Laurentian land, and that air-breathing invertebrates had lived on the areas not reached by water, the progress of development in marine faunas, land faunas, and land vegetation being for the most part contemporaneous. He believed there was no break in the succession anywhere over the European area until the close of the Lower Silurian; and he believed that this break only took place in areas which were then subject to volcanic disturbances. Over the larger areas the depression was gradual, and the succession perfectly continuous from the base of the Cambrian to the commencement of the Carboniferous. The sea-bottom during the Tremadoc, Arenig, and Llandeilo periods was at a greater depth than in any previous period; and though at the close of the Arenig it became much disturbed in some areas by volcanic forces, and covered over by thousands of feet of volcanic matter ejected from submarine volcanoes, which in some cases heaped up sufficient material to enable them to reach above the surface, yet on the whole it must be considered a period of tolerably deep water; and the depression must have been continuous to have allowed these great and rapid accumulations to be again covered over by conformable sediments.

OUTLINE MAP OF EUROPE, SHOWRIAN ROCKS IN DIFFERENT AREAS.



▨ Conglomerates, Sandstones nd slates (deep water accumulations.)

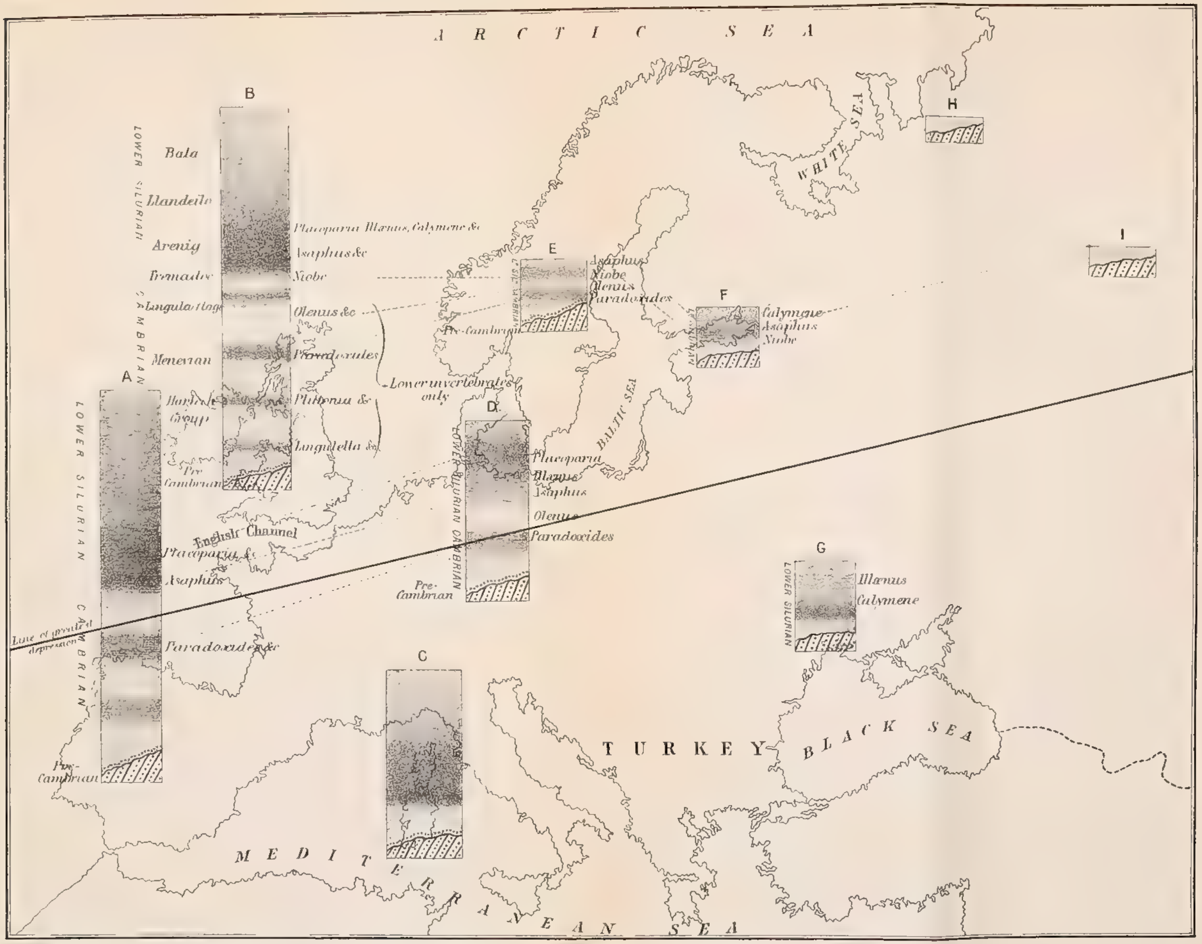
A. Central regions of Spain. (Guadarai

B. Wales (North & South) For the most pa ia)

C. Sardinia. The succession here has no of St Petersburg)

represent generally, the conditions obse tchora &c.) I. Ural Mountains.

OUTLINE MAP OF EUROPE, SHOWING THE COMPARATIVE THICKNESS AND DEPTH OF DEPOSITION OF THE CAMBRIAN & LOWER SILURIAN ROCKS IN DIFFERENT AREAS



▭ Conglomerates, Sandstones and Grits (shallow water accumulations) ▨ Flags and fine sandstone ▩ Schists and slates (deep water accumulations)

A. Central regions of Spain (Guadarama, Montes de Toledo, province of Leon, Daroca &c.)
B. Wales (North & South) For the most part this represents the succession also in France (Brittany &c)
C. Sardinia The succession here has not yet been thoroughly worked out, but this order appears to represent generally the conditions observed here, & also on the South Coast of the Mediterranean (Algeria &c)
D. Bohemia and Bavaria
E. Norway and Sweden (Neighbourhood of Christiania)
F. West coast of Russia (Finland and neighbourhood of St Petersburg)
G. Podolia
H. Shore of the Arctic Sea (region of Petchora &c)
I. Ural Mountains

42. *On* PRORASTOMUS SIRENOÏDES (Ow.).—Part II.

By Prof. OWEN, C.B., F.R.S., F.G.S. (Read June 9, 1875.)

[PLATES XXVIII. & XXIX.]

THE fact that, in the discussion on *Eotherium*[*], Dr. Murie, in his able summary of the Sirenia, made no mention of *Prorastomus*, and that it has not been noticed in any of the papers on new forms, or on derivative hypotheses of the order, which have appeared since 1855, begat a misgiving that the characters adduced in our Quarterly Journal for that year[†] might not have been deemed conclusive of the Sirenian nature of the Jamaica fossil. I therefore submitted it to a fresh scrutiny, and, endeavouring to expose more of it, was gratified by finding that further chiselling of the matrix (a hard grey limestone) exposed so many additional characters as, in connexion with the former evidence of a more generalized structure in this, perhaps, geologically oldest known Sirenian, to lead me to deem them worthy of notice. As the fossil skull is now in almost the state of completeness of that of the *Felsinotherium Forrestii*, I accordingly submit three views, corresponding with those illustrating the instructive memoir by Capellini in the Transactions of the Institute of Bologna[‡], with a conviction that they will prove acceptable materials towards the solution of the problem of the origin and course of modification and variation of the Sirenian type of the mammalian class.

The chief additions to the characters of *Prorastomus*, such as were shown by the reduced figures given in plate xv. vol. xi. of the Quarterly Journal of the Geological Society (1855), are of the base and roof of the cranium, the zygomatic arches, the hind half of the mandible, with the articular surface of the condyle, and the major part of the atlas vertebra.

To the description of the occipital surface (*loc. cit.* p. 542, pl. xv. fig. 1) may be added, that no trace of the sutures between the super- and ex-occipitals remains, the outer half of such sutures being present in a *Manatus americanus* with six of the molars in place on each side of both jaws. This gives evidence of the maturity of the smaller fossil Sirenian. The paroccipitals are broad, compressed from behind forward, and slightly bent, with the concavity backward, as in *Manatus*. In the concavity between the base of the par- and basi-occipitals opens the præcondyloid foramen, as in *Manatus* and *Rhytina*. The basioccipital has been fractured transversely a little in advance of the præcondyloid foramina; and the fore part has been pressed upward for a line's breadth or more above the level of the hind part of that bone. The length of the basioccipital (Pl. XXVIII. fig. 3, 1) is 1 inch 8 lines; and the suture with the basisphenoid (Pl. XXVIII.

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[*] Proc. Geol. Soc. November 18th, 1874.

[†] Quart. Journ. Geol. Soc. vol. xi. p. 541, pl. xv. (1855).

[‡] 'Memorie della R. Accademia delle Scienze dell' Istituto di Bologna,' Serie terza, tom. i. p. 605, tav. i.–iii. (1871).

figs. 3, 5) persists, as shown by Vrolik in his subject of *Manatus americanus*[*], and by Home in the skull of *Halicore malayana*[†]. The longitudinal contour of the basioccipital is wavy, concave below at the hinder half, convex in front, decreasing in breadth as it approaches the basisphenoid. On each side of the basioccipital is a large vacuity, in which appears mesially the petrosal (*Ib. ib.* 16) and laterally the tympanic. The lower (exposed) surface of the latter shows the Sirenoid thickness and convexity.

The basisphenoid expands a little beyond the suture, and the sides bend down, forming a broad and deep arch or concavity downward, as in *Manatus*; but there is no trace of the pair of tuberosities on the basilar tract as in *Manatus*, *Halicore*, and *Rhytina*.

In advance of the paroccipital (4) is the expanded base (8′) of a vertical mastoid ridge (Pl. XXVIII. fig. 1, 4) extending from the hind part of the squamosal (27), between which ridge and the origin of the zygoma (27′) is the upper and hinder arch of the tympanic cavity (*t*). The zygomatic process of the squamosal is vertically broad or deep; its upper border rises and describes a bold convexity; its outer surface is undulated, convex at the upper half, concave vertically below. What appears to be the hind end of the malar part of the zygoma (Pl. XXVIII. fig. 1, 26′) has been displaced from its suture with the squamosal portion (*ib.* 27′). It is of equal or of greater vertical extent, and must have given the zygomatic arch characteristically Sirenoid proportions. The origin of the zygomatic process of the squamosal does not project abruptly backward or upward as in *Halicore* and *Felsinotherium*; it is rather nearer to *Manatus* in this respect, but of more normal character than in any other Sirenian. The squamoso-parietal suture does not rise above the level of the upper border of the zygoma; it extends backward to the exoccipito-mastoid ridge, with an angular depression at the middle of its course more open than in *Manatus*.

The upper wall or roof of the cranial cavity is broken away; but the ridge curving from the frontal to the postorbital angle remains on the left side. The breadth of the brain-case (2½ inches in advance of the foramen magnum) is 2 inches, indicating the Sirenian retention of the breadth of the cerebrum to near the fore end of that part of the brain. In advance of this the cranium contracts to a breadth of 1½ inch, which is in a greater degree than in other known fossil Sirenians, or in any of the recent forms. The superorbital plate of the frontal (*ib.* fig. 1, 12) is of great vertical thickness, and projects with a convex border above the orbit (*o*). This is elliptic, with the long axis parallel with that of the skull. The lower border is formed by the malar (26), which, seemingly entire on the right side, projects a little beyond the upper border of the cavity. The fore part of the orbit is bounded by a thick outstanding subvertical plate of the maxillary (21), with an indication of a small imperforate lacrymal (73) between it and the frontal. The wide suborbital canal (21′) opens

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[*] Bijdragen tot de natuur- en ontleedkundige Kennis van den *Manatus americanus*, fol. pl. iv. fig. 12.

[†] Phil. Trans. 1820, pl. xii. fig. 1.

anterior and close to the antorbital plate of the maxillary; but this does not incline forward and outward in advance of the foramen as in other Sirenians recent and extinct.

I can speak now with more confidence of the extension of the præmaxillary (Pl. XXVIII. fig. 1, 22) by a narrow plate, along the upper and lateral border of the horizontal nostril (fig, 2, *n*) to the frontal (11); but the fractured upper part of the skull still leaves the condition or existence of true nasal bones in *Prorastomus* uncertain.

The condyle of the mandible (29) is transversely extended, is slightly convex in that direction, and more convex in the shorter antero-posterior diameter. From the outer angle of the condyle the bone descends, more vertically and with less curvature than in *Manatus*, to the hind border of the ascending ramus. The outer end of the condyle overhangs the outer surface of the ascending ramus, but is less thick than in *Manatus*. In both rami the condyle, with a small part of the hind border of the ascending ramus, has been separated by fracture from the rest of the ramus and cemented in this dislocated state to the inner surface of the ascending branch anterior and external to it. The angle of the jaw has descended below the level of the horizontal ramus; but to what extent, its fractured state prevents a determination. Nearly 2½ inches of the vertical extent of the ascending ramus is preserved on the right side: the hind border was bent feebly outward as in *Manatus*; the lower border, on leaving the rounded angle, is narrower than in *Manatus*, but thickens as it advances, yet to a less degree than in *Manatus*. The vertical extent of the horizontal ramus at the alveolus of the last molar is 1 inch 8 lines; the extreme thickness there is 9 lines. The lower border of the ramus describes a feeble concave curve from the angle to the symphysis. The fracture of the lower surface of the symphysis, 5 lines in advance of the hind border, indicates some projection, probably like that which characterizes the same part in *Manatus*. The outlet of the dental canal (Pl. XXIX. fig. 4, *s*) is large; it is an inch in advance of the hind part of the symphysis, 2 inches behind the fore part, and widens where it impresses the surface of the bone, upon which the impression indicates the ramification of the nerve and vessel, as in *Manatus*, *Halicore*, and *Felsinotherium*.

There are indications in the left præmaxillary (Pl. XXVIII. fig. 1, 22) of three alveoli, one opening upon the obtuse fore end, the other two upon the contiguous lateral part of the alveolar border: but there is no trace of teeth in these; they had probably fallen out before fossilization. A the præmaxillo-maxillary suture is an indication of the socket of a canine. A diastema, with a feebly concave thin border, intervenes for an extent of about 1 inch 3 lines between the suture or socket of the canine and the foremost upper premolar. This tooth, on the right side, is represented by a long fang, inclined from above downward and backward, with a longitudinal slight indent, indicative of a division of the fang. The position of the roots of two simple-rooted premolars in the lower jaw, which rise in advance of the foremost in place above, shows that this upper tooth may have been the third of the series (Pl. XXIX. fig. 1, *d* 3). The next (*d* 4) is chiefly represented by a root, obliquely directed, like the one in front (*d* 3), with the external longitudinal indent narrower and deeper, more distinctly indicative of two connate fangs, with the base of the crown, to which a fragment of enamel adheres.

The outer, enamelled side of the crown of the tooth (*ib. ib.*, *d* 5) has been pushed inward out of place; it is 4 lines from before backward, 2 lines in extreme vertical extent at the middle of the crown. The anterior fang of this tooth is exposed for 8 lines of its length.

The sixth tooth (first molar, *ib. ib.*, *m* 1) has also the longitudinal much exceeding the vertical diameter of the crown; and the outer exposed side is divided by a widish median indent (*ib.* fig. 3, *i*) into an anterior (*a*) and posterior (*b*) lobe. The fore-and-aft diameter of the crown is 6 lines, the vertical diameter is 2 lines. The outer sides of the two lobes are bulging or convex both vertically and lengthwise; the inner sides are narrower (*a′ b′*). The grinding-surface has been worn to a common field of dentine. Of this tooth two distinct external fangs are exposed (Pl. XXVIII. fig. 1, *m* 1, and Pl. XXIX. fig. 1, *m* 1). The seventh tooth (second molar, *m* 2) shows a similar configuration, with increase of size (Pl. XXIX. figs. 1 and 2, *m* 2 & 7). The fore-and-aft extent of the crown is 8 lines; but the vertical diameter is barely 3 lines. The anterior lobe (*a*, *a′*) is worn to nearly the bottom of the transverse dividing valley (*i*); a feeble angle of dentine marks the summit of a low buttress or fold at the hind part of the front lobe, descending to the outer end of the valley (*i*); the hind lobe (*b*) has its transverse ridge abraded to near the base, but a thin line of enamel next the valley remains. The hind surface of this lobe shows a ridge (*g*) descending from the middle of the back part of the worn upper surface downward and outward to near the base of the crown, with a slight curve; it defines a flat facet (*h*) on the outer half of the hind surface of the crown, the ridge representing a portion of an interrupted "cingulum."

The fore part of the crown of the eighth tooth (third molar, *m* 3, fig. 3) shows a transverse ridge traversing the fore part of the base of the front lobe. The fracture across the skull passes through the front lobe of this tooth; part of the hind lobe remains on the hinder moiety of the fossil skull, and shows the valley deeper, through less amount of wear, than in the antecedent molar; yet the dentine has been exposed upon the hind lobe to a breadth of half a line. The inner surface of the hind lobe has no basal ridge. The transverse breadth of the crown of this molar is 8 lines, the fore-and-aft breadth is 9 lines. The hind surface is imbedded in the matrix; but the character of this part of the molar is given by the antecedent tooth.

The crowns of the fifth, sixth, and seventh of the molar series are preserved in the left maxillary, progressively increasing in anteroposterior extent of crown, and in a more definite external indent marking its division into two lobes. The two outer fangs are distinct on the sixth and seventh teeth; and one of the inner diverging roots is shown on the fractured surface of the eighth tooth (last molar) of this side of the jaw.

In the mandible the root and part of the broken crown of an incisor, apparently answering to the third above, is retained on the right side, as shown in Pl. XXIX. fig. 4, *i* 3, and in figure 2, at *i*, pl. xv. of the original description*. After an interval of 2½ lines the long fang of the canine is exposed, as shown at *c*, Pl. XXIX. fig. 4. After an interval of 10 lines is the fang of a single-rooted premolar ("first" of the grinding series, *ib.* fig. 4, *d* 1); near to this is a similar root of the "second" (*ib. ib. d* 2). The "third" lower premolar is less distinctly shown. In the "fourth," part of the enamelled crown is preserved: it is 3½ lines in fore-and-aft extent. The "fifth" premolar has a similar size and shape; the crown is preserved and is supported on a single fang.

The "sixth" tooth (first lower molar, *m* 1) shows the shallow vertical indent at the middle of the outer side of the crown; and two fangs correspond to the two coronal lobes so indicated. The two fangs are also preserved of the "second molar,' *m* 2 ("seventh" tooth); but the crown is gone or hidden. The opposer of the last upper molar appears to have been lost on the right side; in the left ramus it is in place, and the inner side of the enamelled crown is exposed, showing a slight indication by a shallow vertical groove of its two-lobed structure. The two fangs of this molar, and of the two antecedent ones, are also visible in the left mandibular ramus.

The transverse breadth of crown in the lower molars is less than that in the upper ones; and they are opposed to the inner half of the grinding surface of the teeth above, and this seemingly to a greater degree than in the Manatee. The enamel is thick, and presents a deep brownish tint in the fossil.

The dental formula of *Prorastomus*, according to the indications susceptible of being worked out in the unique fossil, is :—$i\,\frac{3.3}{3.3}$, $c\,\frac{1.1}{1.1}$, d or $p\,\frac{5.5}{5.5}$, $m\,\frac{3.3}{3.3}=48$. The premolars are here so called on the ground of position, smaller size, and simpler structure.

The molars are bilophodont, with two outer and two inner roots, at least in the upper jaw. The premolars are tubercular, or with simple crowns and single roots, or partially divided roots, except, perhaps, in the hindmost above, where the vertical division seems to be complete. The upper true molars (Pl. XXIX. fig. 2) have an anterior basal ridge (*f*) and a posterior oblique partial basal ridge (*g*); each lobe seems to have been a transverse ridge prior to abrasion.

In the enamelled covering of the crown, in its low vertical extent as compared with its antero-posterior and transverse breadths, in the two-ridged structure of the true molars, *Prorastomus* accords with the existing genus *Manatus*, and differs, with it, from the genera *Halicore* and *Rhytina*.

In the excess of the molar series beyond the number "seven," on each side of both jaws, *Prorastomus*, like *Manatus*, departs from the type of the terrestrial vegetable-eaters of the Mammalian class, and gives an interesting indication thereby of a Cetacean character. But the existing *Manatus* departs further from type, developing $\frac{10.10}{9.9}$ in the molar series instead of $\frac{8.8}{8.8}$, as in *Prorastomus*. This earlier

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* *Tom. cit.* p. 543.

and now extinct genus thus adheres more closely to the diphyodont dental type, and not only in number, but in the different proportions and configurations of the teeth, whereby the three true molars are more plainly differentiated from the antecedent premolars. The teeth at the fore part of the jaws, viz. incisors and canines, retain the common type as to number and kind in *Prorastomus*, and have not been subject to so great a degree of suppression, or of individual excess of development, as in existing Sirenians.

In *Felsinotherium* the molar series appears to be represented by $\frac{5.5}{4.4}$. Of these teeth five molars remain in place on the right side of the upper jaw, and three molars on the left side. In the lower jaw so much only of the alveolar part is preserved as to retain three molars in each ramus.

They increase in size, gradually, from before backward, retain the general type as respects roots and enamelled crown of those of *Manatus* and *Prorastomus*, and show an outer and an inner indent in the least-worn hindmost molars, indicative of the bilobed structure; but each lobe is subdivided, as in *Hippopotamus*, into two parts by a longitudinal wavy cleft, and the grinding-surface of the enamel-tissue is further extended by shallow accessory folds. The molars of *Prorastomus* had not this complexity: they were more like those in *Manatus*, and yet had not the fore-and-aft sides of the primary lobes so indented, whereby in *Manatus*, when the crown has been worn as low as in the eighth grinder of *Prorastomus*, the enamel borders, especially of the transverse valley, are more or less wavy. When worn down lower the resemblance in *Manatus* to the similarly worn molars of *Prorastomus* becomes greater.

The molars of *Prorastomus* are more like miniatures of those of *Dinotherium* than of any Sirenian.

As compared with the skull of *Manatus americanus*, the orbit is less advanced in position. In *Prorastomus* the extent from the hind border of the orbit to the fore end of the præmaxillaries is equal to that from the hind border of the orbit to the occipital ridge. The maxillo-præmaxillary or facial part of the skull is also deeper as well as longer in *Prorastomus*. The alveolar part of the maxillary descends vertically below the prominent lower border, or floor, of the orbit for about an inch. In *Manatus* the horizontal plate of the maxillary supporting the malar floor of the orbit is much more extensive, and the vertical part of the maxillary curving down to the outlets of the sockets of the three anterior teeth is less than a quarter of an inch in extent. In *Prorastomus*, also, the penultimate and two antecedent molars are beneath the orbit, and the four anterior premolars are in advance of that cavity; but not any of the molar series are in advance of the orbit in *Manatus*.

If the somewhat thickened border of the zygomatic plate of the squamosal (Pl. XXVIII. fig. 1, 27) is natural and the fractured and dislocated plate of bone beneath (ib. *x*) belongs not to that part of the zygoma, then the squamosal part of the arch is much less deep, as it unquestionably is much less thick, than in *Manatus*, and the zygomatic arch must have shown more normal or ordinary mammalian proportions in *Prorastomus*.

The longer and deeper præmaxillaries accord with the indications of their supporting incisor teeth in *Prorastomus*. The minor relative depth and length of these bones in *Manatus* are associated with the minute size of the single incisor. The mandible is longer in proportion to its depth, and also in proportion to the rest of the skull, in *Prorastomus* than in *Manatus*.

Felsinotherium differs from *Prorastomus* in the greater extent of the downbent fore part of the præmaxillaries, which, as in *Halicore* and in *Rhytiodus*, is in relation to the deep socket for the single large deflected tusk representing the incisive part of the dental formula. The præmaxillary and corresponding part of the mandible continue in *Prorastomus* the horizontal line of the skull, in relation to the three small subequal incisors which are carried on each side of both upper and lower jaws. This is the most marked feature in which *Prorastomus* adheres to the normal mammalian type, while showing the essential characters of the marine herbivore.

Whether the angle of the jaw is produced downward in the degree in which it is in *Manatus*, and especially as in *Felsinotherium*, is undeterminable, as that part is broken off in *Prorastomus*; but this very fracture makes it probable that the Sirenian mandibular character was present in some degree.

In the few comparable parts of the base of the skull the chief difference between *Prorastomus* and other Sirenia, fossil and recent, is in the smaller relative size of the petrotympanics (Pl. XXVIII. fig. 3, 16); they are, as usual, exposed at the large vacuities on each side the basioccipito-sphenoid (ib. 1, 5) characteristic of the order.

In *Prorastomus* the breadth of the skull outside the zygomatic arches is half the length of the skull; in *Felsinotherium* it is less than one half that length.

The upper tract of the cranium in *Prorastomus* contracts anteriorly to the temporal apertures; in *Felsinotherium* it rather expands as it approaches the postorbital prominences.

The zygomatic arches, deep and massive in both Sirenians, are more outwardly arched in *Prorastomus*; they run straight and parallel with the supero-lateral ridges of the cranium in *Felsinotherium*.

The outer nostril in *Felsinotherium* extends back to the parallel of the hind border of the orbit; in *Prorastomus* it does not quite attain the anterior border of the orbit.

In *Felsinotherium* the continuation of the zygoma along the lower border of the orbit is in a line with the rest of the arch, and forms a right angle with the maxillary part where this passes inward to join the body of that bone. In *Prorastomus* the maxillary part of the orbital border passes more gradually inward and upward to the body of the bone.

The external nostril, though horizontal and longitudinally elliptical in *Prorastomus*, is shorter in proportion to the skull and to its breadth than in *Felsinotherium* and recent Sirenia.

In all these differences *Prorastomus*, while retaining the essential Sirenian characters, departs less from the normal forms of the mammalian skull than does *Felsinotherium* and other known extinct Sirenians, and still less than do the existing species.

In the number of teeth developed in the molar series (Pl. XXIX. fig. 3), *Prorastomus* departs, as already observed, from the diphyodont or higher mammalian type, yet only by a single additional tooth, so far as can be made out from the present fossil. In this, however, there are, in advance of the last three grinders, which from their size and structure I have symbolized as true molars, five smaller and simpler teeth, which I have described under the name of premolars. Whether any of these have displaced, vertically, deciduous predecessors cannot be determined in the present unique evidence of the genus*. I incline to think not, and to regard them as answering to the series of teeth which are displaced by permanent premolars in the diphyodont group. In the additional molar tooth of *Prorastomus* we have the last show of "irrelative repetition" which marks the dental series in the Delphinidæ, Zeuglodontidæ, loricate Bruta, marsupial *Amphitheria*, *Myrmecobius*, &c.

The Sirenia are essentially monophyodont. The seeming exception in the upper incisors of *Halicore*, where a small functionless tooth precedes the incisor tusk†, and is shed, leaving for some time traces of its small socket anterior to that of the large tusk, may support the interpretation that such tusk is a functionally developed second incisor, the homologue of *d i* 2 in *Manatus*, and not of *i* 1 in Diphyodonts, preceded by a *d i* 1.

Halicore and *Felsinotherium* depart further from type than do *Halitherium* and *Manatus*, but these still further than did *Prorastomus*. *Rhytina*, by its better-developed brain than in *Prorastomus* and *Eotherium*, and by its adult edentulous condition of jaws, exhibits a still more extreme modification of the Sirenian type.

In *Halitherium*, besides the pelvic ossicles, a rudimentary femur was articulated with an acetabulum, but remained, as in *Balæna*, hidden under the skin.

I infer, as in the case of the similarly concealed metapodials II. and IV. in pliocene and existing Equidæ, that such rudiments of the hind limbs are the result of degeneration, through lack of use or need, from better-limbed prototypal mammals. *Hyracotherium*, *Pliolophus*, *Miolophus*, *Coryphodon*, from the older Eocene deposits, indicate or exemplify a more generalized ungulate type than the hoofed fossils from subsequent Tertiaries, and oppose the idea that the later, more modified, better-defined Artio- and Perissodactyles were derived from distinct primary branches of the mammalian stem.

Prof. Häckel‡ derives Sirenia as follows in his ideal "genealogical tree" of Mammals:—

" SIRENIA = *Phycoceta* . . . .
ZEUGLODONTES = *Zeugloceta*
CETACEA = *Autoceta* . . . .
ARTIODACTYLA . . . .
} from the branch ‘*Ungulata*’
PERISSODACTYLA . . . . from the branch ‘*Pycnoderma*’ of the MAMMALIAN TRUNK."

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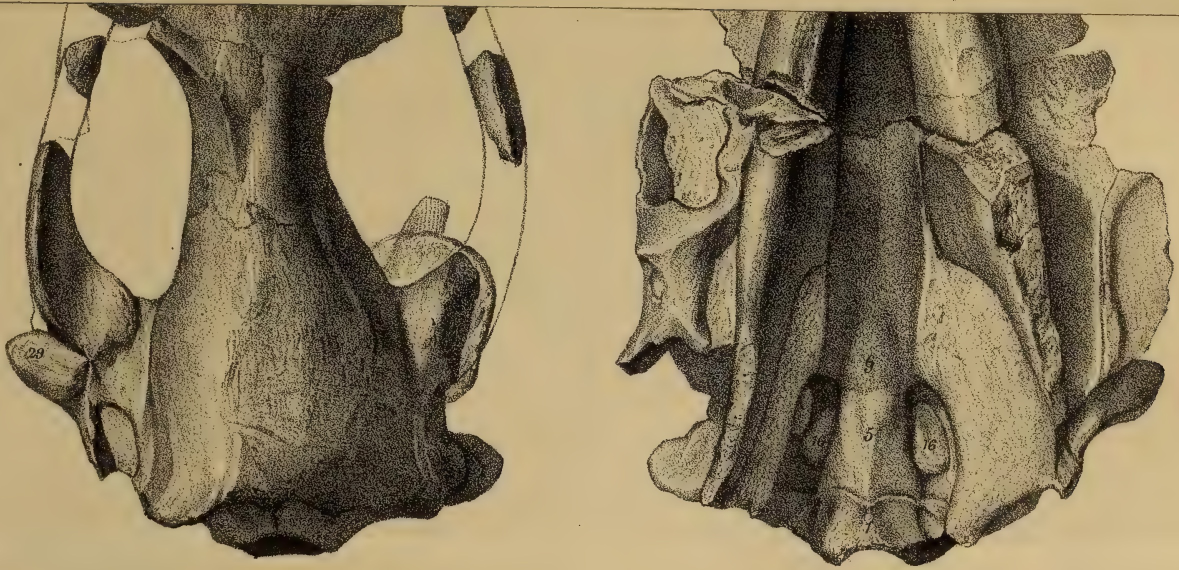
* They are so symbolized in Pl. XVIII. fig. 1.

† Proceedings of the Zoological Society, 1838, p. 40; ‘Odontography,’ 4to, 1840, p. 384, pls. 92–95; Cyclopædia of Anatomy, art. "Teeth," vol. iv. (1852), p. 902, fig. 575.

‡ ‘Generelle Morphologie der Organismen,’ Bd. ii. tab. viii.



G.H.Ford.

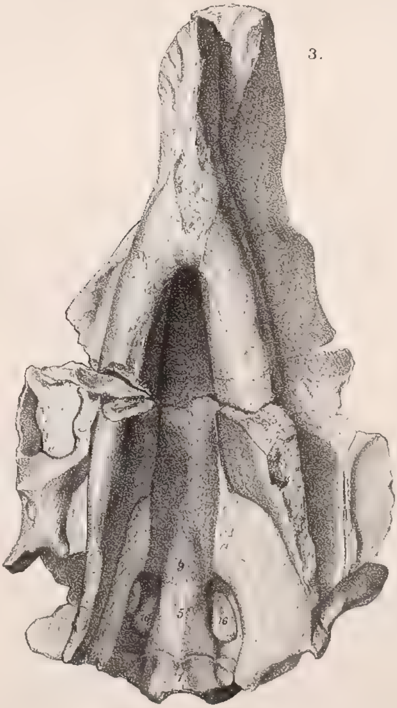
Mintern Bros. imp.

PRORASTOMUS SIRENOIDES.

1.

2.

3.

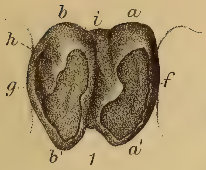


G H Ford

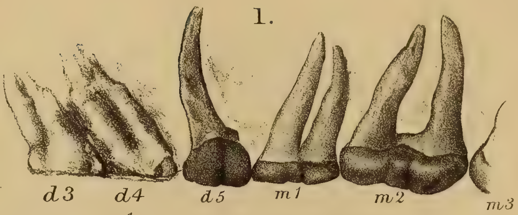
Mintern Bros

PRORASTOMUS SIRENOIDES.

2.



1.



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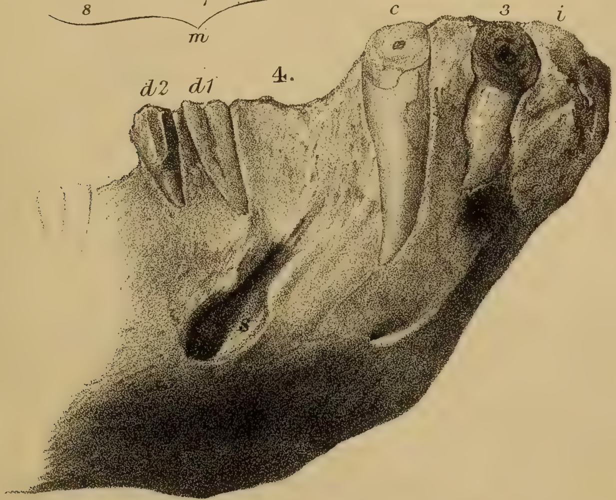
4.



5.

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PRORASTOMUS SIRIENOIDES.

No doubt both *Halitherium* and *Felsinotherium* foreshow the molar pattern of *Hippopotamus*; but *Prorastomus* shows that of *Lophiodon* and *Tapirus*, to which *Manatus* still adheres rather than to any artiodactyle type of molar.

Hence, permitting oneself to indulge in the easy task of feigning hypotheses, one might suggest that both Ungulates and Sirenians diverged at the same remote period from a more generalized (Cretaceous?) mammalian gyrencephalous type—and that the marine Herbivora, in the course of long Eocene and Miocene eons, became subjected to conditions and influences calling out, respectively, analogous modifications of molars, in one tending to an artiodactyle, in other to a perissodactyle character of such teeth.

Prorastomus, by its more generalized dentition and shape of brain, represents a step nearer such speculative starting-point than does any hitherto discovered extinct or existing Sirenian. This it is which gives so great an interest to the West-Indian Tertiary genus, and excites so strong a desire to learn more of the conservable, petrifiable parts of the extinct species.

In the instructive memoir "On the West-Indian Tertiary Fossils"*, by R. J. Lechmere Guppy, Esq., F.L.S., F.G.S., these fossils, chiefly shells, forwarded to him by Mr. Vendryes, of Jamaica†, are referred to Miocene Tertiaries; and it does not appear that any of these specimens were obtained from the compact limestone-bed of *Prorastomus* underlying the general (Miocene?) "carious limestone," at Freeman's-Hall Estate, between the parishes of St. Elizabeth and Trelawney.‡

Further search in the river-course of that locality might be rewarded by the discovery of more parts of *Prorastomus* in the compact limestone there. Any shells or other invertebrate fossils in that formation would be most acceptable, as being likely to afford a clew to its age.

EXPLANATION OF THE PLATES.

Plate XXVIII.

Fig. 1. Side view of the skull of *Prorastomus sirenoïdes.*
2. Upper view of the skull of *Prorastomus sirenoïdes.*
3. Under view of the skull of *Prorastomus sirenoïdes.*

(*These figures are of half the natural size.*)

Plate XXIX.

Fig. 1. Side view of retained molars, left side, upper jaw: the symbols are explained in the text.
2. Grinding surface of right upper penultimate molar, *m* 2.
3. Plan of the molar series, right side, upper jaw: the lower numbers indicate their position from before backward: the upper numbers symbolize the true, or three last, molars.
4. Right-side view of the symphysial part of the mandible and remnants of teeth therein.
5. Hind view of part of the atlas vertebra.

(*These figures are of the natural size.*)

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* Geological Magazine for September and October 1874. † *Ib.* p. 404.

‡ Quart. Journ. Geol. Soc. vol. xi. 1855, p. 541.

43. *On the* GRANITIC, GRANITOID, *and* ASSOCIATED METAMORPHIC ROCKS *of the* LAKE-DISTRICT. Parts I. & II. By J. CLIFTON WARD, Esq., Assoc. R.S.M., F.G.S., of the Geological Survey of England and Wales. (Read June 23, 1875.)

[PLATES XXX. & XXXI.]

Preface.

IN the following memoir I propose to consider all the points of *theoretic* importance connected with the granitic and granitoid rocks of the Lake-District and their associated metamorphic rocks, details and self-evident facts being described at full in the 'Survey Memoir.'

Part I. will treat of the probable pressures under which the granitic and granitoid rocks were consolidated, these pressures being calculated from the evidence afforded by the liquid-cavities contained in the quartz.

Part II. will deal with the case of the Eskdale and Shap granites and the associated altered rocks, on lithological, microscopical, and chemical grounds, the evidence for or against these masses being derived by metamorphism from the surrounding rocks being brought forward.

In Part III. the Skiddaw granite and metamorphosed Skiddaw slates will be treated in a similar manner.

Part IV. will comprehend a like examination of various masses of syenitic granite, syenite, and quartz-felsite, with the rocks metamorphosed around them.

Lastly, Part V. will consist of a summary of results, and a statement of the theoretic points which these support.

PART I.—*On the Liquid-cavities in the Quartz-bearing Rocks of the Lake-district.*

[PLATE XXX.]

CONTENTS.

Introduction.

No one can read Mr. Sorby's masterly and elaborate paper on the Microscopical Structure of Crystals* without being struck with the amount of patient investigation it displays and the host of interesting questions it suggests. During the last few years that it has been my privilege to work in the field among the rocks of the Lake-district it has frequently been upon my mind to apply Mr. Sorby's method of investigation to the granites and other quartz-bearing rocks, in order to see how far inferences drawn from field-observations were confirmed by the microscopic study of the liquid-cavities and their contained vacuities. I have been the more anxious to do this as the relations which the three granitic centres of the district bear to the surrounding rocks vary in each case, and I think there is good reason to infer from geological evidence that the three masses *solidified* under different pressures and conditions.

I. *Geological Relations of the three Granitic Centres.*

1. *General Relations.*—The Skiddaw Granite occurs only in connexion with the Skiddaw Slates, which are extensively metamorphosed around it.

The Eskdale Granite is wrapped round by highly altered rocks of the Volcanic Series of the Lake-district.

The Shap Granite is also for the most part surrounded by volcanic rocks metamorphosed in a similar manner to, but less widely than, those around the much larger Eskdale mass; on the south, however, the granite is in close connexion with the lowermost beds of the Coniston Series, which are altered by it; and granitic dykes occur amongst the Upper Silurian strata.

Various questions are suggested by these relations:—At what period was each granitic mass formed? Was the thickness of superincumbent rocks at all similar in the three cases? Were any or all of these granitic masses connected with the formation of the volcanic rocks?

2. *Skiddaw Granite.*—The Skiddaw Granite, occurring as it does in several inlying masses of small extent (the largest but one mile in length and half a mile in breadth), and being surrounded on all sides by great thicknesses of metamorphosed Skiddaw Slates, would seem to have been solidified in connexion with the Skiddaw Series alone; and, had denudation been carried a little less far than it has been, the existence of granite immediately below would only have

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* Quart. Journ. Geol. Soc. vol. xiv. p. 453.

been surmised from the extensive metamorphism of Skiddaw Slate shown at the surface. There is certainly nothing in the lithological structure or chemical composition of this granite to lead one to infer that it was *directly* connected with the volcanic outbursts which succeeded the Skiddaw-Slate period, since all the *nearest* lava-flows, and indeed the lava-flows of the district generally, belong rather to the doleritic than the trachytic or felsitic class. Whether this granite was formed merely beneath the overlying parts of the Skiddaw-Slate Series, or when some 12,000 feet of volcanic rocks were piled above these, or, lastly, when both Skiddaw Slates and the Volcanic Series were overlain by some 14,000 feet of Upper Silurian strata, it is impossible, from field-observation, to determine. The widely spread and extensive metamorphism around the granite seems rather to point to a deeply seated origin; and the period when the lowest parts of the Skiddaw Series must have been buried most deeply beneath overlying beds was the close of the Upper Silurian, before that vast denudation was effected in Old Red times which removed from *much* of the district not only all the Upper Silurian strata, but all the beds of the Volcanic Series and a considerable thickness of Skiddaw Slates as well.

The *maximum* thickness of strata under which the lower parts of the *known*[*] Skiddaw Slates could have been buried is 38,000 feet; and in all probability the real thickness was less than this; of this total 12,000 feet[†] may be put down to the Skiddaw Slates, 12,000 to the Volcanic Series, and some 14,000 to the Upper Silurians.

3. *Eskdale Granite.*—The Eskdale Granite, for reasons which I have briefly given in a previous paper[‡], and which will be entered into more fully in the Second Part of this Memoir, I believe to have no direct connexion with the *origin* of the volcanic rocks surrounding it, and to have been formed, in all probability, when the topmost beds of the Skiddaw Slates must have been buried beneath some 12,000 feet of volcanic rocks and 14,000 feet of Upper Silurian strata. Since, however, the granite occurs only *in* the Volcanic Series, we may assign 22,000 feet as the *maximum* thickness of rocks under which it could have been consolidated. The very widely spread metamorphism of the Volcanic Series around this granite *tends* to negative the possibility of its having been formed at the close of the Volcanic period, before the deposition of the Upper Silurian.

4. *Shap Granite.*—Lastly, in the case of the Shap Granite, there seems every probability that the period of its formation was the close of the Upper Silurian, in which case the thickness of overlying strata could not have been much more than 14,000 feet. As no volcanic rocks are known to occur in connexion with the Upper

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[*] No *base* to the Skiddaw Series is seen in the district.

[†] This is my estimate for the whole thickness *known*, so that it is certainly an *over*-estimate for that occurring above the granite.

[‡] "The Microscopic Rock-Structure of some Ancient and Modern Volcanic Rocks," Quart. Journ. Geol. Soc. vol. xxxi. p. 388.

Silurian strata, it is impossible to connect this granitic mass directly with volcanic phenomena taking place in that period.

5. *Summary.*—Thus the possible and probable depths at which these various granitic masses may have been formed are as follows:—

		feet.
Skiddaw Granite,	*possibly* less than	12000
	more likely	24000
	perhaps *most* likely	30000 to 38000
Eskdale Granite,	*possibly* less than	12000
	most likely	22000
Shap Granite,	most likely	14000

These figures can of course only be taken as very rough approximations from evidence gathered in the field. It is quite possible that the thickness of the Upper Silurian in its former extension northwards was far less than in the Kendal district; or the reverse may have been the case. The estimated thickness of the Volcanic Series is probably not exaggerated, but it may be underrated. That of the Skiddaw Slates is difficult to determine with any degree of accuracy, owing to the contorted character of the beds, the absence of definite and traceable divisions, and the want of a base-line to the whole series; but it seems likely that the thickness of Skiddaw Slates known in the district is not less than 10,000 or 12,000 feet*.

We have now to see how far an examination of the liquid-cavities in the quartz of these granites and other allied rocks throws light upon the question of *depth of origin.*

II. *Mode of Microscopic Examination, and Precautions taken.*

Mr. Sorby's classical paper has been my main guide in conducting this examination; but it will be as well to state briefly the process employed and the chief difficulties met with in endeavouring to ensure accurate results.

All the specimens examined have been in the form of thin slices, which have been viewed by transmitted light. The power used has been a $\frac{1}{4}$-inch (of Collins), which, with a C eyepiece, magnifies 665 times.

By employing a Jackson's micrometer with the C eyepiece, the divisions being equal to $\frac{1}{10000}$ of an inch, very small cavities and their contained vacuities may be measured.

A necessary result of the examination of thin slices is, that a very large proportion of cavities may be either wholly or partially drained of their liquid; hence in the latter case the bubbles would appear larger than they ought to appear. Besides this there may sometimes be cases of air or vapour caught up originally with the fluid. As ex-

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* See Official Memoir on the Geology of the Northern part of the Lake District.

amples of such sources of error, compare figs. 1–5, in Pl. XXX., with figs. 6–10; in the former cases the liquid-cavities, being comparatively large, have lost fluid, whilst in the latter they have probably remained closely sealed during those long ages which have elapsed since the first formation of the rock containing them. There is this striking difference between the two sets of cavities: whereas figs. 1–5 contain bubbles showing no free movement, the still vacuous bubbles in figs. 6–10 are in a state of constant activity, moving about in the liquid to different parts of the cavities.

At first, making use of a neutral-tint glass reflector, I carefully traced on paper all the best-defined cavities, making a note by the side of those in which the vacuities showed a constant spontaneous movement. I soon found, however, on comparison of a considerable number of drawings, that the fixed bubbles were almost invariably relatively larger than those which showed this free movement; and measurements with the micrometer proved the same. This led me wholly to reject the cavities containing *fixed* bubbles for purposes of measurement; and in every case used in this investigation the micrometer-measurement has been made solely of cavities containing freely-moving vacuities. In Pl. XXX. figures containing fixed bubbles have been introduced for comparison with the others; and all these are marked with a small *f*.

It will at once occur to many that, unless liquid-cavities can be ascertained to be of a very uniform shape, it is impossible to gain a true idea of their actual size by a measurement in one plane alone. That their form is often very irregular is not to be doubted; and, as shown in figs. 1, 4, 58, 59, and 63, they often have more or less tubular processes projecting from them in various directions, which may or may not happen to be in the focus-plane; if the latter, the measurement of the cavity *in one focus* does *not* represent the true size. A fairly reliable measurement may, however, be made in those cases in which the line bounding the cavity is sharply defined all round *in one focus*, and in which the vacuity moves freely to all parts, *keeping all the time in focus*: this is so with most of those figured in Pl. XXX. Even in such cases it may be supposed that minute tubular processes sometimes extend outwards from the focus-plane, only that the bubble, minute as it may be, cannot find entrance into them; an example of such fine tubular processes *in* the focus-plane is seen in fig. 58, the bubble moving freely everywhere except into these tubes. While, however, we must be on our guard against this *possible* source of error, there is little reason why the average great number of good observations should not be relied upon.

It sometimes happens that in cavities of a form similar to figs. 7 and 9 the vacuity moves freely about at one end, but never enters upon the field of the other half. This may be due to the cavity being more shallow at one end than the other; therefore in this case the measurement taken in one plane will be slightly incorrect. Indeed when one reflects upon the many sources of possible error in measurement, and the difficulty of observing a sufficient number of cases to work upon, it seems almost hopeless to get more than a very rough general result.

By a *perfect case*, the measurement of which may be considered fairly reliable, I mean therefore one in which the cavity is of uniform depth and of just sufficient depth to enable the vacuity to move freely to every part without once going out of focus; in such cases every thing will be sharp and clear *in one focus*, and, unless the shape of the cavity be very irregular, the relative size of the vacuity to the whole cavity may be approximately ascertained. Many of the measurements to be brought forward presently were made from such as these, though in others the vacuity has not been seen to move to *every* part of the cavity. From this and similar sources of error it is impossible to expect any thing like an absolute uniformity in the measurements; but when, all extreme cases being discarded, an average is struck, the mean result may be fairly taken to represent the probable truth. The following are examples of this:—

$$\text{No. 1.}\left\{\begin{array}{l}\cdot154\\ \cdot154\\ \cdot154\\ \cdot166\\ \cdot180\\ \cdot180\\ \cdot154\\ \cdot154\end{array}\right\}\cdot162 \qquad \text{No. 2.}\left\{\begin{array}{l}\cdot166\\ \cdot125\\ \cdot200\\ \cdot166\\ \cdot200\\ \cdot180\\ \cdot166\\ \cdot166\\ \cdot166\\ \cdot154\\ \cdot166\\ \cdot142\\ \cdot142\end{array}\right\}\cdot164$$

The above are consecutive measurements from different rock-slices. In No. 1 there are five cases in which the whole liquid-cavity is 6½ times the size of the vacuity, one case in which it is 6 times the size, and two cases in which it is only 5½ times. The mean, ·162, is probably not far from the real truth.

In No. 2 there is one case in which the liquid-cavity is 8 times the size of the vacuity, two cases in which it is 7 times, one case in which it is 6½ times, six cases in which it is 6 times, one in which it is 5½ times, and two in which it is 5 times. Now the mean of these is ·164; but probably the measurements ·200 and ·180 should be discarded, seeing that the majority are considerably below them, and the error is more likely to be on this side than the other; this would reduce the mean to ·155.

The following examples, Nos. 3 and 4, are from slices of Skiddaw Granite, the specimens being taken from spots two miles apart;—

$$\text{No. 3.}\left\{\begin{array}{l}\cdot125\\ \cdot116\\ \cdot142\\ \cdot132\\ \cdot154\\ \cdot154\\ \cdot166\end{array}\right\}\cdot141 \qquad \text{No. 4.}\left\{\begin{array}{l}\cdot132\\ \cdot180\\ \cdot104\\ \cdot200\\ \cdot125\\ \cdot116\\ \cdot125\\ \cdot132\\ \cdot142\\ \cdot166\\ \cdot154\\ \cdot100\\ \cdot166\\ \cdot142\\ \cdot132\\ \cdot142\\ \cdot166\\ \cdot154\\ \cdot132\\ \cdot166\end{array}\right\}\cdot143$$

Although there is here considerable diversity of measurement in the two groups, the means are strikingly similar. If the measurements of ·180 and ·200 in No. 4 are struck out as probable errors, the mean is reduced to ·138, which, considering the number of measurements still below this, is probably yet slightly too high.

In some of the smallest liquid-cavities the vacuity is so small that it looks merely like a black spot moving rapidly about. In one such instance there was the appearance as of two bubbles connected moving about together. These very active spontaneous movements are most curious to watch. In many cases the little bubble seems never to be at rest; nor can I make out that shaking of the microscope-stage has any effect upon the movements, whether they be active or more sluggish. Mr. Bonney suggested to me that the motion might be caused by currents set up in the liquid by unequal heating; I can scarcely fancy, however, that this can be the case, since the liquid-cavities in which the most marked movement takes place are generally so extremely small (often less than $\frac{1}{10000}$ of an inch in diameter) and the motion is so irregular.

The larger bubbles, which probably contain air or gas, do *not* exhibit these active movements; very generally also these larger bubbles are attached to one side of the liquid-cavity, and sometimes markedly drawn out or flattened, as is seen in figs. 1, 41, and 68.

Occasionally small crystals are found in the liquid-cavities besides the vacuity, as figured in Mr. Sorby's memoir; and long fine crystals, probably of schorl, sometimes pass quite through the walls of the cavities, as in figs. 37 and 38.

For the most part the liquid-cavities containing moving vacuities, which alone are reliable for measurement, are extremely small, sometimes less than $\frac{1}{10000}$ of an inch in diameter. Much larger cavities generally occur in plenty; but these seldom exceed $\frac{1}{2000}$ of an inch in length, and in them the bubbles either have no movement or but a very slight or sluggish one.

In Plate XXX. I have figured examples of liquid-cavities from different quartz-bearing rocks of the district, and appended a scale of $\frac{1}{1000}$ of an inch magnified to the same amount as the drawings, and divided into 20,000ths. It will be seen that in most cases the general form of the cavities is rectangular, or more or less irregular; but in some instances, as particularly in figs. 44, 46, 47, 50, and 62, it partakes of the true crystalline form of the quartz, showing a six-sided section, and representing a kind of negative crystallization.

III. *General Results of Examination.*

Preliminary Remarks.—After having made above 500 drawings and measurements, I find the following to be the general results for the various quartz-bearing rocks enumerated below:—

The figures given under *v* represent the means of many measurements taken from different slices of the same rocks at various spots. I cannot but feel, however, that the number of observations is comparatively small, and should therefore like to consider the results obtained as merely preliminary to a more extended investigation, which might be undertaken at some future time under circumstances of greater leisure.

It will be understood that the figures given below represent the relation existing between the size of the liquid-cavity, as a whole, and that of the vacuity; thus, if the latter be one sixth of the former, the relationship is represented by ·166.

	v.	Pressure, *p.*
Skiddaw Granite	·130	52000
Eskdale Granite	·166	42000
” ” , veins from................	·166	42000
Quartz Felsite (Elvanite) dykes from the Eskdale Granite	·125	53000
Shap Granite...........................	·150	46000
Ennerdale and Buttermere Syenite (or Syenitic Granite)...........................	·190	35000
Quartz Felsite of St. John's Vale	·170	40000
Quartz Felsite of Fairy Crag, Crag Bridge	·140	49000
Quartz Felsite (Elvanite) dyke of Armboth and Helvellyn	·150	46000
Mean of all the above	·158	44000

Making use of the formula given in Mr. Sorby's paper,

$$p=369,000\frac{V-v}{1+V},$$

derived from other formulæ which it is not necessary here to reproduce, and taking his observations on the trachyte of Ponza as a basis, we have

$$369000 \frac{\cdot 3 - v}{1 + \cdot 3} = p + 4000 \text{ feet.}$$

supposing the temperature of consolidation to have been 360° C. (680° F.). Substituting in this formula the values given in the column of our table headed v, we procure the results given in the second column, which represent in each case the pressure of rock in feet necessary to compress the liquid so that it would fill the cavities *at a temperature of* 360° C. (680° F.), which is a dull red heat visible in the dark.

It must be clearly borne in mind, however, that these figures do not represent the *depth* at which consolidation took place, but only the amount of *pressure*; for, as Mr. Sorby has remarked (*l.c.* p. 491), "in some cases the pressure was probably much greater than that of the superincumbent rocks, for otherwise they could not have been fractured and elevated; whereas in other cases it may have been much less if the internal pressures had been in any way relieved." This is a consideration of the highest importance in our present line of argument, as we shall presently see.

1. *Skiddaw Granite.*—I think it is pretty certain that the Skiddaw Granite was never covered up under a *greater* thickness of strata than 38,000 feet; and probably this is above the mark; whereas, assuming for a moment that the measurement ·130 is a correct one to work upon, according to Mr. Sorby's formulæ the calculated pressure of rock in feet is 52,000, a difference of 14,000 feet. Here, then, the pressure being greater than that of the overlying rocks, it is likely that these last were elevated and fractured at the time, and *unlikely* that the internal pressures were relieved by volcanic action. If the reverse were the case, the calculated *pressure* being under the estimated *thickness* of 38,000 feet, we might gather an argument for the direct connexion of this granitic mass with volcanic outbursts by which much of the pressure might have been relieved.

As it is, however, confirmation is rather given to the view that the granite was formed beneath the above *estimated thickness* of strata and under circumstances of great additional pressure, by means of which that elevation and disturbance of the district was effected which took place at the close of the Upper Silurian period.

In the consideration of this case, however, it might become a question whether the difference of 14,000 feet between *calculated pressure* and *estimated thickness of overlying beds* is not too great—although, when one considers the enormous amount of quiet force required for the gradual elevation and contortion of 38,000 feet of strata, this extra pressure at a temperature of only 360° C. (680° F.) does not seem any too great for the work, in fact it becomes doubtful whether it be enough.

I have already said that 38,000 feet is very likely the greatest depth at which the Skiddaw Granite could have been consolidated; but, in all probability, the depth was considerably less. Even if we suppose the Upper Silurians to have maintained the same thickness northwards which they have in the Kendal district, it is doubtful whether we can include more than 4000 feet of Skiddaw Slate in the total thickness of strata overlying the granite at the period of its formation. This being the case, the estimated *thickness* would be reduced to 30,000 feet; and the difference between that and the *calculated pressure* thus becomes 22,000 feet, to be expended in the elevation and contortion of the overlying rocks.

It is curious to contrast these results with those of the increase of temperature on descending through the earth's crust. We are supposing that the Skiddaw Granite was consolidated at a depth of 30,000 feet and at a temperature of 360° C. (680° F.). Now, if we take the rate of increase of heat with depth as given by Mr. R. W. Fox*, viz. 1° for every 49 feet, we shall find that the temperature of 360° C. (680° F.) would be attained at a depth of 30,900 feet. On the other hand, Mr. Hunt's estimate, as quoted by Mr. Sorby in his paper, would give this temperature at the much greater depth of 53,000 feet, agreeing very nearly with the calculated *pressure* of rock in feet given as the result of microscopic examination. It is hard to say which is the mean rate of increase most to be relied on; and it is quite possible that, even if Mr. Hunt's estimate be nearest the truth at the present epoch, that given by Mr. Fox might represent the conditions at an early Palæozoic period, before cooling of the earth's crust had gone so far as it now has. Thus, to sum up in the case of the Skiddaw Granite, we may say it is probable, from geological evidence, that this granite was consolidated at a depth of about 30,000 feet. Other evidence gives a temperature of 350° C. (662° F.) for this depth beneath the surface; microscopic evidence gives a *pressure* in rock of 52,000 feet at the temperature of 360° C.; this *calculated pressure* exceeds the *estimated* depth by 22,000 feet, which excess may have been applied to the work of elevation and contortion of the overlying 30,000 feet of rock.

We now proceed to see how such arguments are borne out by other cases in the same district.

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* Brit. Assoc. Report for 1857, p. 91. [An important paper by Prof. Mohr has just appeared (Neues Jahrbuch, 1875, 4th part, p. 371) on the cause of earth-temperature. A boring near Berlin gave a temperature of 38·5° R. at a depth of 4042 ft. The rate of increase of temperature per 100 ft. was found to diminish in a constant ratio with the depth, so that at 5170 ft. it would be 0. Even taking a lower decrease in the ratio $\left(\frac{1^\circ}{100}\right.$ R. instead of $\left.\frac{5^\circ}{100}\right)$ the constant temperature is reached at 13500 ft. This, says Mohr, refutes the doctrine of plutonic fire, and leads to the inference that the internal temperature is the result of actions going on in the outer crust. It is needless to remark upon the bearing of this on Mr. Mallet's theory of vulcanicity. At the same time it seems to render it more probable than ever that granite has not been formed at a high temperature, though under conditions of great pressure and moisture.—Oct. 1875].

2. *Eskdale Granite.*—It has already been shown that, in all probability, judging from purely geological evidence, the Eskdale Granite was consolidated at a less depth than that of Skiddaw, 22,000 feet being a probable estimate. We should therefore expect to find that the microscopic evidence would likewise show a less pressure; and this is found to be the case, thus:—

	Depth.	Pressure.
Skiddaw Granite	30000	52000
Eskdale Granite............	22000	42000

The same argument may be applied here as in the case of the Skiddaw Granite. The *calculated pressure* being so much in excess of the *estimated thickness* of overlying strata, it is *unlikely* that the pressure was relieved by volcanic action; and it is rendered more probable that the excess of pressure was spent in the work of elevation and contortion. Now it is curious to observe that the excess in this case is nearly the same as in the last, viz. 20,000 feet as against 22,000; but whereas in the former a *pressure* equal to 22,000 feet in rock at 360° C. (680° F.) elevated a *thickness* of 30,000 feet of strata, in the latter case one of 20,000 upheaved but 22,000 feet. Are we, however to regard the temperature as the same in both cases? Taking Fox's mean, the temperature at a depth of 22,000 feet would be 259° C. (499° F.). Taking the microscopic value of $v = {\cdot}166$, we obtain from Mr. Sorby's formula (δ),

$$t = \sqrt{684462V + 12144} - 110,$$

the result that the temperature requisite to expand the fluid so as to fill the cavity under the pressure of the elastic force of its vapour *only* is 244° C. (471° F.); and therefore under the *pressure* of 42,000 feet the temperature required must have been much greater than 244° C. (471° F.), and consequently very much greater than the calculated temperature (according to Fox) at the depth of 22,000 feet. Hence we have this result on comparing the cases of the Skiddaw and Eskdale Granites:—

1. *Skiddaw.*		2. *Eskdale.*	
$v = {\cdot}130$. If $p = 0$, the minimum temp. $= 208°$ C. (406° F.).		$v = {\cdot}166$. If $p = 0$, the minimum temp. $= 244°$ C. (471° F.).	
Depth, from geological evidence. ......30,000.		Depth, from geological evidence. ......22,000.	
Sorby's estimated temperature of solidification of granites, 360 C. (680° F.).	Fox's calculated temperature at this depth, 350° C. (662° F.).	Sorby's estimated temperature of solidification of granites, 360° C. (680° F.).	Fox's calculated temperature at this depth, 259° C. (499° F.).

$v = \cdot 130.$

∴ Calculated *pressure* (p) $= 52{,}000$.

This gives:—

Downward pressure	Surplus pressure
↓	↑
30,000.	22,000.

$v = \cdot 166.$

∴ Calculated *pressure* (p) $= 42{,}000$.

This gives:—

Downward pressure	Surplus pressure
↓	↑
22,000.	20,000.

From the nature of the investigation, to quote Mr. Sorby's words, "the true heat can only be determined when the approximate value of the pressure is known; and the pressure cannot be deduced unless we can in some way or other approximate to the temperature." But the *pressure*, since it does not necessarily mean the mere thickness of overlying rocks, contains two elements, only one of which can be arrived at by purely geological evidence; so that, arriving at the other element by microscopic investigation, it should, if reliance can be placed on the microscopic results, when taken together with the temperature, be able to effect an equivalent amount of work in the various cases dealt with. For example, if an upward, or surplus, pressure of 22,000 feet at 360° C. elevate 30,000 feet, what should be the temperature for an amount of upward pressure represented by 20,000 to elevate 22,000 feet? A simple calculation gives 290° C. as the necessary temperature. Or, if 30,000 feet are elevated at a temperature of 360° C. by an upward pressure of 22,000 feet, what amount of upward pressure is required to elevate 22,000 feet at the same temperature? The answer is 16,000. This last result, put in a tabular form, appears thus:—

3. *Skiddaw.*

Downward pressure (D. P.) = 30,000.
↓
$t = 360°$ C.
$v = \cdot 130$
$\therefore p = 52{,}000.$
↑
Surplus pressure (S. P.) = 22,000.

4. *Eskdale.*

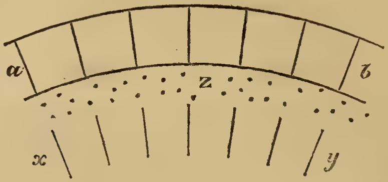
D. P. = 22,000
↓
$t = 360°$ C.
$v = \cdot 166$
$\therefore p = 42{,}000.$
↑
S. P. = 16,000.

The discrepancy between the value of 22,000 + 16,000 and 42,000 is not very great when the uncertainty of some of the data is remembered.

It is possible that the use of the terms *downward pressure* and *surplus* or *outward pressure*, and that of the arrows as symbols, while helping to give clearness in one direction may impart ambiguity in another. The case may be put in another form as follows:—

Let the arch *a b* (fig. 1, p. 580) represent a thickness of 30,000 feet of rock overlying the consolidating granite *z*, and the lines *x*, *y* represent pressure from below. If the liquid-cavities show a total pressure in feet of rock of 50,000, that pressure must be dependent on the tension of the overlying rock, and might be reduced to less than what corresponds to 30,000 feet if there were contraction of the

Fig. 1.—*Diagram illustrating the Action of Pressure on Granite in Process of Consolidation.*



subjacent mass and the solid crust were supported like an arch. As soon, however, as upheaval commences, the effective pressure must be at least equal to that which the overlying rock can resist, and the difference between the total calculated pressure and that represented by the thickness of overlying rock must represent its tensile strength. Hence we may further conclude that solidification of the quartz was approximately completed before the total pressure was thus diminished in amount by the fracture of the overlying mass and loss of tensile strength. If in the above example the *total* pressure was only 30,000, no upheaval could take place.

a. Wastdale-Head Granitic Veins.—It will be seen from the table given on p. 575 that the value of *v* is the same as in the case of the main Eskdale mass. The veins from which this result was gathered are very small strings running among the metamorphosed volcanic rocks and proceeding from the granitic mass of Wastdale Head, which is separated from the great granitic area of Eskdale by at least two miles of highly altered rocks, probably underlain at no great depth by granite.

b. Quartz Felsite (Elvanite) Dykes from the Eskdale Granite.—The dykes yielding the results given in the table (p. 575) are closely associated with the Eskdale Granite. The calculated *pressure* from the value of *v* in this case is 53,000, supposing the temperature of consolidation to have been the same as that of the granite, viz. 360° C. (680° F.); this is 11,000 in excess of the granite. It is impossible for these dykes to have consolidated at a greater depth than the granite from which they proceeded; and therefore we must look to some other cause for this marked difference of result. The subject will be best considered when we deal with other quartz felsites of a similar character.

3. *Shap Granite.*—In the case of the two granitic centres already dealt with we have seen that the microscopic investigation helps to bear out the idea formed, from geological evidence in the field, as to their relative depths of origin. Referring back to the table given on p. 575, we should now expect to find that the value of *v* for the Shap Granite would be considerably higher than it was found to be in the other cases. Instead of this, however, it is lower than in the case of the Eskdale Granite (the latter being ·166 and the former only ·150), though higher than that of Skiddaw.

The least temperature at which this granite could have been consolidated, if $p=0$, is 228° C. (502° F.). I have already stated my belief that geological evidence is strongly against its having been *consolidated* at a much greater depth than 14,000 feet, at which depth, according to Fox's mean, a temperature of 168° C. (335° F.) would be, under ordinary circumstances, attained.

It is somewhat striking that this discordance with other similar microscopic results should be in the case of a granite which is easily distinguished from all other granites by the extraordinary development of large felspar crystals throughout its mass.

One of the three following suppositions must be true:—1. The microscopic measurements may be wrong. 2. The application of measurements, even if approximately correct, may be upon a wrong principle, and no results may be trustworthy. 3. The circumstances under which the Shap Granite was formed may have been in great measure peculiar to itself.

With regard to the first supposition, it may be answered that measurements taken from very different parts of the granitic mass give nearly the same mean result. In reply to the second it may be urged that it is difficult to believe that the many striking results brought forward by Mr. Sorby are merely coincidences. On the whole it seems most likely that the third supposition is the true one; and we must proceed to inquire into this possible peculiarity of circumstances.

In the first place we may infer from the coarsely crystalline nature of the rock, and the development of unusually large and numerous crystals of felspar, that the cooling or consolidation proceeded very slowly, the felspar separating first in a crystalline form, and, by so doing, probably setting free sufficient heat to enable the quartz to retain its soft condition for a time*. Now quartz, in solidifying, passes through a viscous state, while felspar solidifies more rapidly on account of its tendency to crystallize, and passes at once from a fluid to a solid condition†. Hence, may we not suppose that the fluid-cavities occurring in the quartz of this granite were enclosed at a much greater depth than 14,000 feet a depth perhaps equal to that at which the Eskdale Granite was consolidated, and that, while the quartz remained in this viscous condition,—containing fluid-cavities, the granitic magma ate its way up among the overlying strata, aided by the great pressure from below, and finally became *solidified* at no greater depth than 14,000 feet?

If the above supposition have any truth in it, we may further believe that the Shap Granite represents a part of the granitic magma underlying large areas of the district at the close of the Upper Silurian, at depths varying from 22,000 to 30,000 feet, which was enabled to eat its way nearest the surface at this point (Shap); whilst in other cases solidification took place at a greater depth, and granite of a different character resulted. If this be so, we may

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* See Durocher "Sur l'Origine des Roches Granitiques," Comptes Rendus, vol. xx. p. 1275.

† Durocher.

regard the mass of Shap Granite as representing an unsuccessful effort towards the formation of a volcanic centre. Had we, indeed, evidence amongst the higher strata of the Upper Silurian or in the Old Red period of volcanic outbursts in this district, and were the nature of these volcanic products such as are likely to have proceeded from the Shap Granite as the *base* of a volcanic centre, we should have good reason to affirm that in the Eskdale Granite, the Shap Granite, and the trachytic or felsitic lavas we saw an epitome of volcanic action—the deeply-seated origin, the very bottom of a volcanic neck, and the lavas poured out at the surface. It is *possible* that such volcanic outbursts *did* take place in the earlier part of the Old Red period; but if so, the enormous amount of denudation (to which reference has already been made) which took place during Old Red times, must have completely destroyed all traces of the volcanic products.

This view of the relation which the Shap Granite bears to the Eskdale is rather strengthened by the fact that the metamorphism around the area of the latter is much more intense and widely spread than around that of the former. If any force be allowed to the above considerations, it becomes all the more clear that these granites can bear no direct relation, as sources, to the great series of *Lower* Silurian volcanic beds in the midst of which they occur, but that they are more recent in date.

The relations of the Eskdale and Shap Granites may be thus put in a tabular form:—

5. *Eskdale.*

$v=\cdot166$. If $p=0$, the min. temp. $=244°$ C. (471° F.).

Depth, from geological evidence.

Top of Upper Silurian.

22,000.

Sorby's estimated temperature of solidification of granites, 360° C. (680° F.).	Fox's calculated temperature at this depth, 259° C. (499° F.).

$v=\cdot166$

∴ calculated *pressure* (p) = 42,000.

This gives:—

Downward press	urplus pressure
↓ 22,000.	↑ 20,000.

6. *Shap.*

$v=\cdot150$. If $p=0$, the min. temp. $=228°$ C. (442° F.).

Depth, from geological evidence.

Top of Upper Silurian.

14,000.

Sorby's estimated temperature of solidification of granites, 360° C. (680° F.).	Fox's calculated temperature at this depth, 168° C. (335° F.).

$v=\cdot150$

∴ calculated *pressure* (p) = 46,000.

This gives:—

Downward pressure	Surplus pressure
↓ 14,000.	↑ 32,000.

It would seem, then, that the only alternative to this mode of considering the relationships of the granites under consideration is to believe that granite may be formed, or may have been formed, at a depth of 14,000 feet, and that the measurements of the liquid-cavities and their vacuities are delusive and of no value.

Mr. Sorby, who has very kindly glanced through these pages, is of opinion that the suggestion given above as to the Shap Granite would be quite satisfactory if we could assure ourselves that, when the rock was driven into its present position, the quartz was sufficiently solid to withstand the pressure resulting from the enclosed heated liquid, or the temperature at the same time reduced.

4. *Ennerdale and Buttermere Syenite and Syenitic Granite.*—This rock might be regarded in part as a syenitic granite, since it contains quartz as well as hornblende, though the mica is often absent and the hornblende very variable in quantity. It forms a wide spread, ranging north and south for about 9 miles, and adjoining the Eskdale Granite at the foot of Wastwater. Through a large part of its course it forms the boundary between the Volcanic Series and the Skiddaw Slates, but in the south occurs wholly amongst the volcanic rocks. Both Skiddaw Slates and Volcanic beds are much altered in its neighbourhood, the alteration sometimes extending to a distance of more than a mile from the mass. In appearance the rock is very different from the Eskdale Granite, though the quartz is generally interstitial and not crystallized, and the hornblende is small in quantity.

The value of v in the liquid-cavities of the quartz in this rock is greater than in any of the other cases (see table, p. 575), being ·190. This, at a temperature of 360° C. (680° F.), indicates a pressure of 35,000 feet in rock. The lowest temperature at which solidification could take place, supposing $p=0$, is 267° C. (512° F.).

The question now arises whether we can consider this wide-spread mass to bear any direct relation, as source, to the Volcanic Series. I have stated my reasons elsewhere* for believing this not to be the case; the beds of lava are not apparently such as would proceed from such a source, although much of the ash is markedly felsitic. If the mass does represent a source of volcanic products, it must, as we now see it, have furnished materials for the uppermost beds of the series only; and in that case the depth at which the rock became consolidated was probably very slight,—but a few thousand feet. If this be so, then the value of v should, theoretically, be much greater than .190, and, if microscopic results be worth any thing, should more closely approximate to that yielded by the quartz in the trachyte of Ponza, which has been shown by Mr. Sorby to be ·3, indicating a pressure of 4000 feet at a temperature of 360° C. (680° F.).

Granting, however, that the microscopic results *are* of some value, the observed value of v in the case of the Ennerdale Syenite shows a *pressure* of 35,000 in feet of rock; and, if not consolidated under merely a few thousand feet of rock, it may be referred with probability to about the same period as the formation of the Eskdale

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* Official Memoir on the Geology around Keswick.

Granite—close of Upper Silurian,—and the depth at which it was consolidated could not have been greater than that given for the granite, viz. 22,000 feet.

Whether the difference in appearance and composition between the two rocks be the result of a slightly different depth of consolidation, or due to a more immediate connexion with both Volcanic Series *and* Skiddaw Slates in the case of the syenite, it is difficult to say; probably the latter has most to do with it.

Tabulating, as in the former cases, we obtain the following:—

7. *Ennerdale and Buttermere Syenite.*

$v = \cdot 190$. If $p = 0$, the min. temp. $= 277°$ C. (512° F.).

Depth, from geological evidence.

Top of Upper Silurian.

......22,000.

Sorby's estimated temperature of solidification of granites, 360° C (680° F.).

Fox's calculated temperature at this depth, 259° C. (499° F.).

$v = \cdot 190$

$\therefore$ calculated pressure $(p) = 35{,}000$.

This gives:—

Downward pressure ↓ 22,000.

Surplus pressure ↑ 13,000.

5. *Quartz Felsite of St. John's Vale.*—This rock differs from the last mainly in the quartz being crystallized, instead of being mostly interstitial, and in the base being markedly felsitic, though containing porphyritically imbedded felspar crystals. It occurs in connexion with the junction-beds of the Skiddaw and Volcanic Series. The value of v is $\cdot 170$, the *pressure* corresponding to this being 40,000.

The arguments used with regard to any volcanic connexion between the Ennerdale Syenite and the rocks of the Volcanic Series apply almost equally well to this case, and need not be repeated in full. Did we find among the volcanic rocks a well-marked series of lavas of the nature of quartz-trachytes or felstones, we might be inclined to regard these masses (not more than 1 mile long) as old volcanic necks; but in the absence of any such, and in the presence of the evidence furnished by the liquid-cavities in the quartz, it seems more reasonable to conclude that the rock was consolidated under the pressure of the beds of the Volcanic Series and those of the Upper Silurian.

Thus we have:—

8. *Quartz Felsite of St. John's Vale.*

$v = \cdot 170$. If $p = 0$, the min. temp. is 248° C (478° F.).

Depth, from geological evidence.

Top of Lower Silurian.

......26,000.

Sorby's estimated temperature of solidification for granites, 360° C. (680° F.).	Fox's calculated temperature at this depth, 304° C. (580° F.).

$v = \cdot 170$;

$\therefore$ calculated pressure (p) $= 40{,}000$.

This gives:—

Downward pressure ↓ 26,000.

Surplus pressure ↑ 14,000.

With regard to this and the other quartz-felsites we have yet to notice, it may be remarked that the crystals of quartz are generally double pyramids without intermediate prismatic surface, and that they have impressed their form upon the felsitic matrix. Now a compound of felspar and quartz melts almost as readily as felspar (Cotta); and when the silica began to crystallize out, the disengaged heat would help to keep the more felsitic base for a time in a partially melted state; and then solidification would probably take place rather rapidly, owing to the preponderance of felspar. Thus the different appearance of quartz-felsites from granites is very probably due to the final solidification taking place more rapidly in the former than in the latter, owing to the felspar in the one and the quartz in the other being the last to solidify, the felspar not passing through a viscous state. And if we compare two such rocks as the Shap Granite and this Quartz Felsite of St. John's Vale, we may perhaps conclude that the former solidified more slowly and at a higher temperature than the latter, but probably also under a less pressure of overlying rocks.

a. Quartz Felsite Dyke of Armboth and Helvellyn.—This very beautiful rock forms a narrow dyke extending for many miles through the Volcanic Series; and although it cannot be traced up to the St. John's Quartz Felsite, there is little doubt, judging from its similar character, that it has proceeded from some part of that mass.

The value of v (·150) given in the table, is the mean of observations taken from widely different parts of the dyke, and points to a *pressure* of 46,000 feet, or 6000 feet more than the main mass from which it probably proceeded. It will be remembered that somewhat similar dykes running off from the Eskdale Granite showed an even greater excess of pressure over the main mass. Thus we have:—

	v	p
Eskdale Granite	·166	42,000
„ „ veins....................	·166	42,000
„ „ , quartz-felsite dykes from..	·125	53,000
Quartz Felsite of St. John's	·170	40,000
„ „ dyke of Armboth	·150	46,000

This gives an excess of 11,000 in the one case and of 6000 in the other. Mr. Sorby has shown that while the granite of St. Austel, in Cornwall, indicates a pressure considerably less than some of the elvans, yet the mean of all the observations on the Cornish granite is 9700 feet more than the mean for the elvans; and upon this he remarks:—"This, I think, is a very satisfactory result, since the association of these rocks clearly proves that granite must have been consolidated at a considerably greater depth than elvans."

The conditions of consolidation in such narrow dykes as most of these are must certainly be very different from those in a large mass; and in most cases it would seem probable that the rate of cooling must have been very rapid, taking place between vertical walls of rock at a vastly lower temperature, and that the pressure on all sides must have been very great and perhaps scarcely comparable with the pressure acting upon a mass of solidifyiug granite.

6. *Quartz Felsite of Fairy Crag.*—This is a small area of rock, very similar, on the whole, to that of St. John's Vale, and occurring solely among the Skiddaw Slates at some little distance from the edge of the Volcanic Series. It will be seen from the table on p. 575 that the value of v rather nearly approaches that of the Skiddaw Granite, the former being ·140 and the latter ·130. This relation would indicate, if the microscopic results be at all trustworthy, that the two rocks were consolidated under somewhat similar pressures; and accordingly we find the following when tabulated and compared:—

9. *Skiddaw Granite.*

$v=\cdot 130$. If $p=0$ the min. temp. $=208°$ C. (406° F.).

Depth, from geological evidence.

....

Top of Upper Silurian.

......30,000.

Sorby's estimated temperature of solidification of granites, 360° C. (680° F.).	Fox's calculated temperature at this depth, 350°C. (662° F.).

$v=\cdot 130$;

∴ calculated *pressure* (p) $=52{,}000$.

This gives:—

10. *Quartz Felsite of Fairy Crag.*

$v=\cdot 140$. If $p=0$, the min. temp. $=218°$ C. (424° F.).

Depth, from geological evidence.

....

Top of Upper Silurian.

......27,000.

Sorby's estimated temperature of solidification of granites, 360° C. (680° F.).	Fox's calculated temperature at this depth, 315° C. (600 F.)

$v=\cdot 140$;

∴ calculated *pressure* (p) $=49{,}000$.

This gives:—

Downward pressure	Surplus pressure	Downward pressure	Surplus pressure
↓	↑	↓	↑
30,000.	22,000.	27,000.	22,000.

The conditions of solidification must evidently have been somewhat different in the two cases to produce rocks differing from one another in character as these do; but the *general* agreement of the results in these and other examples drawn from microscopic investigation and geological field-evidence is satisfactory.

General Remarks.—The mean value of v for all the above rocks is ·158, which corresponds to a *pressure* of 44,000 in feet of rock. Sorby's mean for the Cornish granites is 50,000; and if the Lake-district *granites* be considered apart from the other rocks mentioned in the table on p. 575, the mean of *pressure* in feet of rock for them alone becomes 47,000, a very near approximation to that of the Cornish granites.

Arranging the rocks we have been considering in order of the values of p, and placing in a parallel column the minimum temperature at which consolidation could have taken place in each case if $p=0$, the following result appears:—

Hunt's results, 1 in 85.	Fox's mean, 1 in 49.		Temperature, if $p=0$.	Pressure at 360° C.
238° C.	406° C.	Ennerdale and Buttermere Syenite	267° C.	35000
271	463	Quartz Felsite of St. John's Vale ...	248	40000
284	486	Eskdale Granite	244	42000
310	537	Shap Granite	228	46000
310	537	Quartz Felsite dyke of Armboth and Helvellyn	228	46000
330	565	Quartz Felsite of Fairy Crag, Crag Bridge	218	49000
350	599	Skiddaw Granite	208	52000

Upon the left are placed other two columns, giving the temperature at depths of the *pressure*-value, according to Fox's and Hunt's estimates of increase on descending. In the foregoing parts of this paper I have preferred to use Fox's mean of 1 in 49 as probably representing the truth more nearly in early Palæozoic times than it may now; and on this supposition we find that all the temperatures at depths varying from 35,000 to 52,000 feet are above 360° C. (680° F.), and range from 400° C. (752° F.) to 600° C. (1112° F.).

If these results be compared with the tables given by Mr. Sorby on pages 495 and 496 of his memoir, the general agreement is found to be satisfactory.

Of course it can by no means be taken as certain that the quartz of all granites finally became solid at a temperature of 360° C.; and some of the discrepancies in the results brought forward may well be due to this difference in the temperature of solidification*. These

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* See note on p. 577.

discrepancies may also be owing, in part, to variation in the amount of salts held in solution, the rate of expansion of water varying with that amount. It is possible, again, that in *very minute* cavities the liquid has been appreciably *stretched*, and thus we may be led to fancy the pressure greater than it really was. To all these points of uncertainty Mr. Sorby has alluded in his paper.

IV. *Summary.*

1. Granites and granitoid rocks may sometimes have been the deep foci of volcanic phenomena, and at other times represent masses formed deeply beneath the surface, consolidated from a state of aqueo-igneous fusion, and widely metamorphosing the overlying strata.

2. Such deeply formed rocks must have been subject in their formation to great pressures, partly from the weight of overlying rocks, partly from internal pressures acting chiefly from below; we may call the first *downward pressure*, and the second *surplus* or *outward pressure*.

3. If the *outward pressure* be relieved by volcanic action, the *whole* pressure to which the consolidating granite in an adjacent part is exposed may be little more than that represented by the *depth* or *downward pressure*.

4. If the *outward pressure* be *not* relieved, the total pressure may be very much more than that represented by the depth; and this unrelieved outward pressure may do work in elevation and contortion of the overlying rocks.

5. In case 4 the metamorphism effected would *probably* be much more widely spread than in case 3.

6. The microscopic examination of the relative size of the liquid-cavities and their vacuities in the quartz of granitic and granitoid rocks furnishes a probable means of estimating the *pressure* under which the cavities were filled.

7. This *pressure*, being of a twofold character, does not give any idea of the relative values of *downward* and *surplus pressures*, unless an approximation to one of these be known. If the depth or *downward pressure* be known, the surplus represents the *outward*, or *vice versâ*.

8. Example.—If the microscopic examination gave a *pressure* of 50,000 feet in rock for a certain granite, and it were known from geological field-observation that in all probability the rock could not have been consolidated at a greater depth than 30,000 feet, there is a surplus of 20,000, which would probably be spent in the work of elevation, contortion, and metamorphism of the overlying rocks. If, on the other hand, the microscopic examination gave a *pressure* of only 30,000 feet, and geological observation tended to show that the depth of formation was probably 30,000 feet, we might infer that most likely the *outward pressure* was relieved by volcanic phenomena*.

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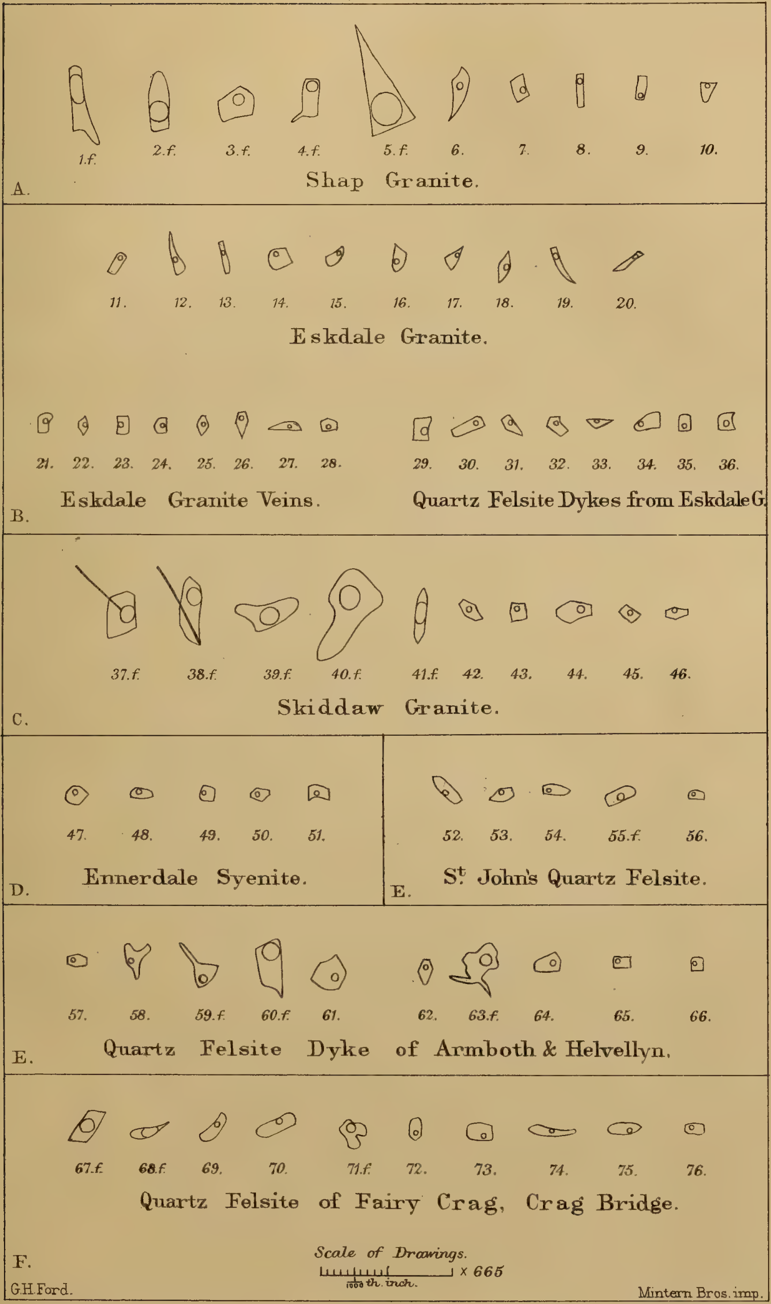
* In most, if not in all cases, however, of volcanic activity, there would be an excess of unrelieved pressure; and this would be sufficient to account for the very general upheaval prevailing over volcanic areas.



LIQUID CAVITIES IN GRANITOID ROCKS OF THE LAKE DISTRICT.

9. It can be shown from the geological examination of the Lake-strict that none of the granitoid rocks were probably consolidated at a *greater* depth than 30,000 feet, while the *pressures* derived from microscopic examination range from 35,000 to 52,000.

10. The Skiddaw and Eskdale Granites, formed at a maximum depth of 30,000 and 22,000 feet respectively, both indicate a large surplus of pressure, probably acting outwards and effecting elevation, contortion, and metamorphism.

11. The Shap Granite, *consolidated* at a maximum depth of 14,000 feet, shows also a large surplus of *pressure*; and, from its nearness to the surface and its distinct character from the large Eskdale mass probably formed at the same time, it may be taken to represent an *immature* volcanic vent. It seems likely that this granite was partly *formed* at a much greater depth than 14,000 feet, but finally *consolidated* at this depth.

12. Microscopic examination yields nearly the same value for the mean of *pressure* under which the Lake-district granites were formed as for those of Cornwall.

13. The quartz-felsite (elvanite) dykes appear to have been formed in this district under a greater *pressure* than the rocks from which they proceeded; but the circumstances under which consolidation took place in the two cases are not strictly comparable with one another.

EXPLANATION OF PLATE XXX.

Examples of Liquid-cavities in the Granitic and Granitoid Rocks of the Lake-district.

A. Figs. 1–10. Liquid-cavities in the Shap Granite; of these, figs. 1–5 have vacuities not freely moving in the liquid.
B. 11–20. Liquid-cavities in the Eskdale Granite.
21–28. Liquid-cavities in veins from the Eskdale Granite.
29–36. Liquid-cavities in quartz-felsite (elvanite) dykes from the Eskdale Granite.
C. 37–46. Liquid-cavities in the Skiddaw Granite; of these, figs. 37–41 have vacuities not freely moving in the liquid, and figs. 37 and 38 show crystals of schorl passing through the cavities.
D. 47–51. Liquid-cavities in the Ennerdale Syenite, or Syenitic Granite.
E. 52–56. Liquid-cavities in the Quartz Felsite of St. John's Vale; fig. 55 shows a vacuity not freely moving in the liquid.
F. 57–66. Liquid-cavities in the Quartz Felsite dyke of Armboth and Helvellyn; in fig. 58 the vacuity moved freely throughout the cavity *except* into the tubular processes; in figs. 59, 60, and 63 the vacuities did not move freely in the liquid.
G. 67–76. Liquid-cavities in the Quartz Felsite of Fairy Crag, Crag Bridge, near Shap; of these, figs. 67, 68, and 71 have vacuities not freely moving in the liquid.

Note.—All the figures are magnified to the same degree; and the scale is appended to the Plate. Those cavities which contain fixed vacuities are denoted by a small *f* placed after the number of the figure.

PART II.—*On the Eskdale and Shap Granites with their associated Metamorphic Rocks.*

[PLATE XXXI.]

CONTENTS.

Introduction.

In the first part of this memoir the two granitic masses of Eskdale and Shap have been considered in connexion with the liquid-cavities enclosed in the quartz of each. The evidence afforded by these seemed clearly to indicate a deeply seated origin; and other considerations were brought forward, all tending to negative the idea of an immediate connexion between the granitic masses and the volcanic rocks *around them,* in the sense of volcanic continuity. The question now arises, If these granitic masses were formed beneath a great thickness of overlying rocks, can we point to the rocks out of which they may have been so formed? I think that we can, and may affirm with great probability that the granite was produced, in great measure at all events, by the extreme metamorphism of the volcanic rocks, such as we now see surrounding it on all sides. That it was exclusively due to the melting-down by aqueo-igneous fusion of these rocks I would not venture to assert; in all probability the heated mass below partly ate its way upwards, at the first, to within reach of the volcanic series, *the rocks of which were then metamorphosed to such an extent as to assume the granitic form and structure.* The evidence for this, in the lithological character, in the microscopic structure, and in the chemical composition of the metamorphosed volcanic rocks, will form the substance of the following pages.

For views of previous writers on this subject, see appendix, p. 602.

I. *Lithological Character.*

1. *General relations.*—I have already alluded in a previous paper [*] to the extreme alteration which many of the beds of volcanic ash have undergone, and given my reasons in some detail for considering very trap-like beds to be merely altered strata of originally fragmentary origin [†]. It is therefore only necessary to state here that a perfectly gradual passage may be traced from beds of volcanic ash in which every separate fragment is clearly discernible, through others in which the original ashy structure is only revealed by weathering, to rocks, immediately in the proximity of the granite, of a close trap-like texture, with imperfect felspar crystals frequently developed porphyritically, fully charged with finely disseminated mica, and occasionally showing free quartz clearly visible to the naked eye, outlying patches of a fine-grained granite being in some cases met with at a little distance from the main mass.

That there are occasional sudden transitions from a less altered to a much more highly altered rock, is only what might be expected when it is considered that we have a series of beds of all degrees of coarseness and fineness, and very probably differing somewhat from each other in their chemical composition. It may readily be imagined that a fine volcanic dust, when much metamorphosed, would present a somewhat different appearance from a coarse ash or breccia altered under similar conditions: one kind of bed may yield itself more readily to metamorphism than another; hence, while in some cases the junction of these altered rocks with the granite may be sharp and definite, in others a much more gradual passage is observable. The general order of change met with on approaching these granitic masses, and more especially that of Eskdale, is the following, subject of course to the causes of variation just mentioned.

2. *First Stage.*—At a distance, frequently of several miles, from the nearest granite, the outlines of the fragments forming a bed of ash or breccia are hazy and indistinct, except on the weathered surfaces. Also the finer material between the larger fragments seems often to have acquired a kind of flow around them, giving rise to a streaky-looking rock, the streaks, however, being discontinuous and quite unlike the comparatively regular and continuous though contorted lines observable in some undoubted felstone-lavas, such as those of Wales and that in connexion with the Coniston Limestone west of Shap. If the ash be wholly fine-grained, a nearer approach is made to the appearance of viscous flow presented by many highly silicated lavas; but even in this case remains of original lines of bedding, the passage laterally into a less altered-looking rock, and

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[*] "The Microscopic Rock-Structure of some Ancient and Modern Volcanic Rocks," Quart. Journ. Geol. Soc. vol. xxxi. p. 388.

[†] See also the Survey Memoir on the Geology of the Northern part of the Lake-district, by the author.

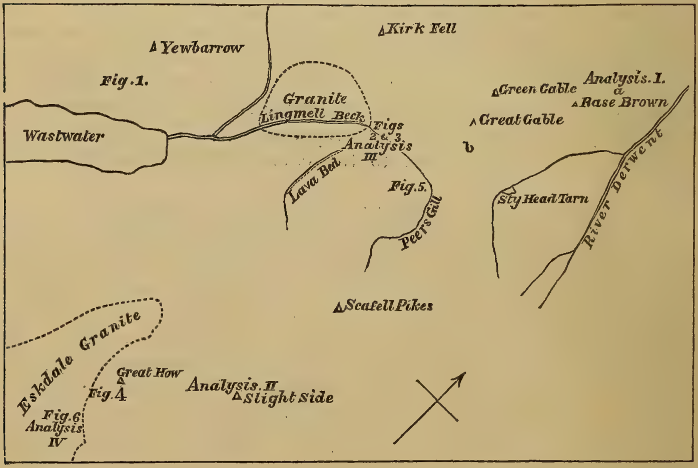
the frequent porcelainic appearance of these beds are often sufficient to indicate the original nature of the deposit.

3. *Second Stage.*—The next stage is that the altered rocks begin to assume a marked purple tint, and minute specks of mica appear, which increase in abundance and are sometimes collected into nests as the granite is more nearly approached.

4. *Third Stage.*—Finally, there are developed in this purplish micaceous base many small crystals of felspar, which often have an irregular and hazy outline; and occasionally quartz also becomes visible. Such extremes of metamorphism represent, indeed, examples of fine-grained granite, which in outward appearance are intermediate between the true granitic mass and the less highly altered rocks, often retaining something of their old ashy character on the weathered exterior.

5. *Boundary-lines of granite.*—Nevertheless it is generally the case that the transition from the metamorphosed ashes, or the very fine-grained granite, to the true granite, appears somewhat sudden, the rock for the most part only losing its dark and purplish-blue hue and becoming lighter in colour immediately at the junction. In the case, however, of metamorphosed coarse ashes or breccias,

Fig. 2.—*Sketch Map of part of the Lake-district, to show the positions of rocks figured on* Pl. XXXI., *and of those analyzed* (*see* p. 597). Scale $\frac{7}{12}$ inch to 1 mile.



No geological details are placed upon this map, as they will be found fully shown upon the published Survey maps.

a. Position of highly altered ash figured in the Survey Memoir on "the Geology of the northern part of the Lake-District," plate ii. figs. 15 and 16.

b. Position of highly altered bedded ash figured in the paper entitled "Notes on the Microscopic Rock-Structure of some Modern and Ancient Volcanic Rocks," Quart. Journ. Geol. Soc. vol. xxxi. plate xvii. fig. 10.

the granitic appearance sometimes comes on at a considerable distance. Thus, certain of the coarse ash-beds of Slight Side (Scawfell), a mile from the nearest granite seen at the surface, have a very granitic look at a little distance, weathering in the same sort of way; and it is sometimes almost impossible to draw any definite line separating the undoubted but yet highly altered coarse ash or breccia from a distinctly crystalline rock verging on a good typical granite (Example, East side of Great Moss, head of Eskdale).

What has been here said is true of both Eskdale and Shap granites; but in the case of the latter the metamorphism has neither spread so widely, nor are there any undoubted cases of outlying patches of what may be called *bastard* granite, such as occur about Scawfell Pikes near the Wastdale and Eskdale granitic masses; in some instances, however, at a distance from the granite, altered coarse ash puts on more the appearance of granite than does much of the finer altered ash *close* to the granitic edge.

While alluding to the oftentimes sharp line of division between the purple, micaceous, and often porphyritic rock, and the true granite, it is worth while to notice the patches of dark, fine-grained, and very micaceous granite which frequently occur in the midst of the granite of Shap. Such patches, having generally a more or less rounded outline, seem to be very largely made up of small dark mica flakes mingled with a less amount of quartz and felspar, the felspar very seldom appearing in porphyritic crystals, as is so characteristic of the granite in general. Now the line of junction between the typical Shap granite and these highly micaceous dark patches is *quite as sharp* as that between the granite and the general mass of metamorphosed rocks around, and sometimes more so; therefore it would be unwise to say positively that the granite cannot be the result of the extreme metamorphism of the ashy beds, *because* the junction between the two is in many cases so definite.

II. *Microscopical Structure.*

A great many examples of these highly altered rocks having been examined microscopically in thin slices, I will describe in general terms the structure exhibited by specimens of the various lithological stages already mentioned. The rocks showing the streaky lines often curving round fragments of various sizes have been figured and described in my previous paper before this Society*, and in the Survey Memoir descriptive of the Keswick district; therefore it is sufficient to note the following facts regarding them, at the present time. The positions from which the rocks referred to were obtained are indicated in the sketch map (fig. 2, p. 592).

1. *First Stage. Felstone-like (and streaky) altered ash.*—General base often appears very fine-grained, and under crossed prisms is dark, with minute points of light. On a close inspection of this dark ground with a high power, it seems certain that the darkness

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* The Microscopic Rock-Structure of some Ancient and Modern Volcanic Rocks.

is mainly due to an immense number of very minute particles of chlorite, which frequently take the form of flowing lines around imbedded fragments or crystals, thus giving rise to the streaky appearance.

2. *Second Stage. Felstone-like with a purplish hue.*—Very good examples of this stage of alteration may be met with in Great Gable and many other parts around Wastdale.

The base, though somewhat felsitic, shows under crossed prisms a dark ground with scattered points of light. This dark ground seems mainly due to the presence of innumerable minute particles of brown mica, apparently taking the place of the chloritic particles observed in the previous stage. There generally occur in this base a few indistinct, altered fragments of felspar, occasionally a long tube-like crystal, more or less epidote, and a few specks of pyrites.

In some cases, as in the example from Bell Rib, Yewbarrow (Pl. XXXI. fig. 1), the brown mica particles are collected in clusters, in the midst of some of which are black patches, probably caused by decomposition of the same. In such instances as these, the rock, though often fine-grained, occasionally shows its ashy structure (as in the figure) or distinct lines of bedding on the outside, while it breaks with a conchoidal fracture and is often exceedingly trap-like within.

Then there are other cases in which, while the general base appears felsitic, the scattered particles seem to be partly chlorite and partly brown mica; and there occur, in many spots, small needles of felspar, which however, only appear under crossed prisms, and have sometimes a disposition to set *round* the larger crystals, and fragments. Besides this setting of the crystalline needles, there seems to be in some cases a general tendency to a flow of the granules (chloritic and micaceous) among which they are imbedded; but this only appears where there are comparatively large fragments in the field around which it may take place. It is a curious fact that, in the rather exceptional cases in which the small crystalline needles occur, they are not visible except under crossed prisms; in ordinary light the very same part of the base appears felsitic (hazy ground with scattered particles), which, when polarized light is used, and the prisms are crossed, shows the fine needles. Of course it is quite possible that in such cases we have, mingled with the highly altered fragmental rocks, some of the true lavas; but the great thickness of some of these rock-masses (as between Cold Pike and Wrynose) and the insensible gradations into unmistakable ash rather tend to negative this view; and if so, we are led to regard the *semi*crystalline structure as produced under special circumstances by intense alteration.

3. *Third Stage. Purplish base with imperfect crystals porphyritically imbedded.*—In this third marked stage the mica particles are more clearly developed and occur in great numbers, frequently collected into groups, as seen in Pl. XXXI. figs. 2, and 3*; they are also more distinctly flaky, and are sometimes collected thickly around the edges of imperfectly formed felspar crystals, as if pushed outwards

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* See the upper and right-hand portion of the disk.

on the growth of the latter. In the examples shown in figs. 2 and 3, from a point in Lingmell Beck close to the granite junction (Wastdale Head), the base is hazy and felsitic in ordinary light (fig. 2), though having brown and greenish mica-flakes scattered over it and in groups, with some grains of magnetite and pyrites. But in polarized light, the ground shown in fig. 2 * appears under crossed prisms as in fig. 3. As the axes of the prisms are slowly brought at right angles to each other, the numerous small felspar crystals seen in the figure gradually become distinct, whereas, before, the hazy white base gave no indication of their existence; sometimes, however, with a $\frac{1}{4}$-inch objective and a strong light, *very faint* outlines of some of the crystals may be recognized. This may indeed be called a crypto-crystalline structure.

In other cases the felspar is distinctly and more largely developed, both as orthoclase and plagioclase, and appears on the surface of the rock generally in the form rather of felspar spots than of distinct felspar crystals. Fig. 4 is an example taken from near the Eskdale granite, west of Great How, which shows the crystalline structure apparently carried a step further than in figs. 2 and 3. It should be noticed that figs. 1 to 6, are all magnified to the same degree for the sake of direct comparison.

4. *Fourth Stage. Bastard granite.*—At the base of the northern slopes of Scawfell Pikes, rather less than three quarters of a mile from the nearest granite of Wastdale Head, occur several patches of rock, to be described in detail elsewhere, which, viewed on the outside, seem closely allied to the surrounding altered ashes, but when examined with the aid of the microscope seem rather to belong to the granites. An example of such is shown in Pl. XXXI. fig. 5, under polarized light. In these cases the base shows a transition between the semicrystalline felsitic structure of the last stage, as seen in figs. 2, 3 and 4, and the more defined and coarsely crystalline structure of the true granite, as seen in fig. 6 (same scale). The example drawn (fig. 5) is from a mass at the foot of Peers Gills, beneath Flass Knotts, which can only be mapped separately from the surrounding less altered ash rocks by means of a dotted, uncertain line, on account of its somewhat more crystalline appearance, though in some parts of this mass the original ashy bedding is still seen on the weathered exterior with considerable distinctness.

Viewed microscopically, a good deal of free quartz is found to be present; but this is not generally visible in hand-specimens with the unassisted eye. The felspar crystals are of various sizes and both orthoclase and plagioclase; some are altered completely except around the edges. The mica is both light-brown and pale-green, the latter in greatest abundance and showing colours under crossed prisms (see brightly banded portions in fig. 5). Both epidote and pyrites also seem to occur in these rocks, and perhaps some magnetite.

5. *Fifth Stage. Granite.*—From this last stage of metamorphism (for I do not think any one can resist the united evidence of field-work and microscopic examination to such gradual metamorphism)

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* Lower and left portion of disk.

the transition is easily made to well-developed granite, being in fact a passage, in this last case, merely from a fine-grained granite to a more coarsely grained one. Fig. 6, representing the microscopic structure, under polarized light, of a fine-grained portion of a specimen from the edge of the great Eskdale granitic mass, is drawn on the same scale as the preceding figures; and the difference between this and the last is no greater than would be found to prevail between fig. 6 and a still coarser part of the granite. In this last figure the quartz appears as irregular areas, interfering with one another, and sometimes containing small crystalline needles as well as included portions of the base and the usual complement of liquid-cavities; the felspar is both orthoclase and plagioclase, an example of the latter being shown in the centre of the drawing; and the mica seen in the area represented is of a lightish brown colour*. The specimen thus figured was near that from which fig. 4 was drawn, the line separating the two being pretty well defined.

What has been hitherto said in the description of microscopic character will apply equally well to the case of the altered ash-rocks around the Shap granite and to those around the Wastdale and Eskdale granite, with the exception that, the metamorphism being less widely spread in the former case, there are fewer examples of the streaky felstone-like rocks, and no good examples of the last stage described under the head of bastard granite. Nevertheless there are some very curious cases of quartz-felsites, sometimes with quartz apparently replacing large felspar crystals, such as those that occur usually in the Shap granite. One remarkable instance of this is among highly altered rocks just beneath the Coniston Limestone, at Shap Wells; and in New Inn Gill, distinct large felspar crystals occur imbedded in the matrix of a quartz-felsite, somewhat micaceous.

In Pl. XXXI. fig. 7, is represented, on a scale one half that of the other drawings, an actual junction of the highly altered ash-rock and the granite. In the specimen the line of junction is tolerably well marked; but under the microscope the change appears much less definite, and seems to be in great measure one of degree. The altered rock, *a* to *b*, is virtually a quartz-felsite with numerous little specks of brown mica and having an occasional string of coarser grain, *c c*, running off from the granite through it. The large crystals of felspar and the larger flakes of mica come on rather suddenly, but are at first imbedded in quite the same sort of felsitic matrix as prevails in the adjoining rock, only that it is coarser-grained; and from this to the fully developed granite there is but a step. In the figure, that half of it representing the granite shows a large crystal of plagioclase felspar, a large area of quartz with enclosed portions of base, and an irregular mica flake of some size.

III. *Chemical Composition.*

1. *Rock-analyses.*—It now remains to be seen how far the views hitherto advanced as to the gradual passage from altered ash-rocks

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* The large and long fragment near the base of the disk and rather to the right is brown mica.

to granite are borne out by the results of chemical analysis. The analyses* given below have been made for me by Mr. John Hughes, F.C.S., No. 1 having been already brought forward in a former paper on "Ancient and Modern Volcanic Rocks"†.

No. 1 is an analysis of the very compact felstone-like rock of Base Brown, figured in the paper just quoted and in the Survey Memoir, and which probably represents an originally fine-grained ash in which metamorphism has developed (as already described) a large amount of chlorite, frequently collected along streaky flowing lines.

No. 2 represents the composition of the highly altered coarse ash of Slight Side, within a mile of the nearest granite at the surface, and weathering in a granitoidal fashion.

No. 3 gives the composition of one of the purplish and semi-porphyritic specimens of altered rock, close to the granite. Its microscopic structure is shown in Pl. XXXI. figs. 2 and 3, the specimen being taken from the course of Lingmell Beck, near the junction.

No. 4 is an analysis of the Eskdale granite, taken from a specimen near the edge, south of Great How.

	I. Altered ash, Base Brown.	II. Altered ash, Slight Side.	III. Altered Con. Trap, Lingmell Beck.	IV. Granite, S. of Great How.
Silica	69·673	68·421	59·151	73·573
Alumina	14·492	15·855	19·212	13·750
Lime	2·296	2·016	5·208	1·064
Magnesia.............	·324	·792	1·909	·396
Potash...............	4·554	3·338	2·933	3·512
Soda	3·017	5·627	4·217	4·315
Ferrous oxide	2·784	2·855	5·192	2·103
Ferric oxide	·442	·172	·879	·615
Bisulphide of iron	·410	....	·360	....
Phosphoric acid	·343	·204	·439	·012
Sulphuric acid........	·205	....	trace	....
Carbonic acid	·660	trace	trace	trace
Loss on ignition	·800	·720	·500	·660
	100·000	100·000	100·000	100·000

2. *Remarks on the analyses.*—If Nos. 1, 2, and 4 be compared, it will be seen that the analyses come very close to one another, the chief difference between the granite (No. 4) and the other examples being an increase of silica of 4 or 5 per cent in the former case and a slight diminution in the percentages of alumina and lime. When,

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* For the positions of the rocks analyzed, see map, p. 592.

† Quart. Journ. Geol. Soc. vol. xxxi. p. 388.

however, the analysis of the specimen taken from a point nearest to the granite, is contrasted with these, a more marked difference is seen, the amount of silica being 14 per cent. less than that in the granite, and that of alumina, lime, and ferrous oxide considerably more.

It will be at once acknowledged that so few analyses of so large an area of rocks can but give a very general idea of the true average composition; and it would be very unwise to affirm that No. 3 necessarily represents the average composition of the altered rocks close to the granite. It has, indeed, been already pointed out that the microscopical structure of this specimen shows it to be more than once removed from the typical granite; and an analysis of the rock whose microscopic structure is represented in fig. 5 might give a somewhat different result. It may well be, in fact, that the specimen chosen for analysis from near the granite, in this instance, was from a rock differing *originally* in a more or less marked degree from the neighbouring masses, as considerable differences are known to prevail amongst these volcanic rocks as a group; and indeed, if we compare No. 3 analysis with analyses of the contemporaneous traps of the district[*], we find them strikingly similar, thus:—

	Contemporaneous Trap. Brown Knotts near Keswick.	*Contemporaneous Trap.* Iron Crag near Keswick.	*Altered Contemporaneous Trap?* Lingmell Beck, Wastdale.
Silica	60·718	59·511	59·151
Alumina	14·894	17·460	19·212
Lime	6·048	5·376	5·208
Magnesia	1·909	1·801	1·909
Potash	2·354	3·705	2·933
Soda	2·843	3·093	4·217
Ferrous oxide	6·426	4·926	5·192
Ferric oxide	1·405	1·271	·879
Bisulphide of iron	·395	·604	·360
Phosphoric acid	·281	·115	·439
Sulphuric acid	·103	·086	trace
Carbonic acid	1·660	1·569	trace
Loss on ignition	·964	·483	·500
	100·000	100·000	100·000

So that it seems probable that the analysis No. 3 may be that of a contemporaneous trap. Upon the western side of Lingmell I have traced such traps for a considerable distance, until, unable to follow them further amongst such highly altered rocks, I represented them as dying away upon the mountain-side, one pointing to this very spot, near the granite[†]. Such a result as the analysis now gives is therefore particularly interesting and satisfactory.

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[*] Quart. Journ. Geol. Soc. vol. xxxi. p. 388.

[†] See "Lava Bed," on map, p. 592.

I think therefore, we may rather conclude that the composition of the contemporaneous traps is not essentially changed by their metamorphism, and that the associated ash is either more highly silicated from the first than the lava-flows, or, what seems less likely perhaps, an excess of silica has been introduced by metamorphism. At any rate, as the ash-deposits form the bulk of the volcanic rocks, and the analyses of both fine and coarse altered ash so well agree with each other and with that of the granite, there is no *chemical* reason why metamorphism should not convert such rocks into granite, the occasional lava-beds forming a very slight hindrance to so wide an action.

It would require a much more extended series of analyses to establish the metamorphism from the chemical evidence alone; but this, taken in connexion with the petrological and microscopic passage, is of considerable interest and importance.

3. *Order of chemical changes.*—If, however, the analyses of altered ash-rocks here given may be trusted as presenting a fair idea of their average composition, it is clear that no addition of chemical constituents is required to convert them into granite, with the exception perhaps of a small percentage of extra silica. Now Mr. Sorby has shown (Brit. Assoc. Report, 1857, p. 92) that the materials of both quartz and mica may be derived from felspar which has lost a part of its alkaline bases, and that such a metamorphism must be the result in great part of highly heated water disseminated through the rock. We know that when the Eskdale granite was formed great quantities of highly heated water were present; for the liquid remains sealed in millions of minute cavities, and the size of the vacuous bubble in each cavity points to the temperature and pressure at and under which the liquid was enclosed; may we not, therefore, conclude that when these volcanic deposits were buried beneath overlying rocks to depths of from 15,000 to more than 20,000 feet, they were subject to the metamorphic influence of highly heated water, and that the various stages of metamorphism were something like the following:—1st, the felspathic material (being decomposed somewhat, and robbed of a part of its alkaline bases) was partly converted into chlorite, some of the excess of silica and alumina going perhaps towards the formation of garnets, so plentiful in the ash-rocks at that stage of alteration; 2nd, this chlorite, which at the first may be regarded as a hydrous mica, became converted in great part into true mica, the magnesian mica appearing first and the potash-mica following, as more alumina was set free by the continued separation of silica; 3rd, all the constituents became more or less crystalline, the mica in the manner indicated; the felspar, formed from the reconstituted felspathic material existing in the rock at the outset, was united with the quartz in one stage of granitic formation, so as to give rise to a quartz-felsite base; but the two minerals finally separated, the felspar crystallizing first and the quartz solidifying interstitially.

4. *On the Phosphoric Acid present in the Volcanic Series.*—In a paper recently brought before this Society by Mr. Hicks, "On the

occurrence of Phosphates in the Cambrian Rocks"*, some interesting points as to the connexion of phosphoric acid with volcanic rocks were brought forward and discussed. Is the phosphoric acid found in eruptive rocks derived from sedimentary deposits through which they may have broken? or are these eruptive rocks themselves the sources of the phosphoric supply to all sedimentary beds?

If we glance at the accompanying Table, showing the relative amount of phosphoric acid in some of the volcanic rocks of Cumberland, we must be struck by the large proportion as compared with that in the associated granite, while the metamorphosed trap (?) rock close to the junction contains the largest amount.

	Phosphoric acid.	Carbonic acid.
No. 1. Lava, Iron Crag, near Keswick	·115	1·569
No. 2. ,, Brown Knotts ,, ,,	·281	1·660
No. 3. Felstone-like altered ash, Base Brown	·343	·660
No. 4. Felstone-like altered coarse ash, Slight Side	·204	trace
No. 5. Probable lava-bed, highly altered, close to granite, Lingmell Beck	·439	trace
No. 6. Granite, (Eskdale) S. of Great How.........................	·012	trace
No. 7. Felstone (contemporaneous) of Aran Mowddwy	·089	trace

Side by side I have placed in this Table the percentages of phosphoric and carbonic acids; and it is an interesting result to notice that as the one increases the other decreases. Since phosphoric acid is not separated from lime by heat alone, and carbonic acid is readily so separated, have we not, in these inverse proportions, another argument for a great change having been effected among the original constituents of these volcanic rocks by extreme metamorphism? For it should be observed that the two lava-beds standing first in the list do not occur in the very metamorphosed region; and of the three following examples, that contains the highest percentage of phosphoric acid which probably represents a highly metamorphosed bed of lava.

With regard to the high percentage of carbonic acid in Nos. 1 and 2, it may be thought that these beds have been more exposed to infiltration from above than the others; but I do not think this can possibly be the case, since these lavas are certainly *lower down* in the series than Nos. 3, 4, and 5, and it seems more reasonable to infer that an equivalent quantity of carbonic acid may have existed in the other examples, but has been driven off by metamorphism, acting more forcibly at one area than another.

If we compare the felstone-like altered ashes of Cumberland with the undoubted contemporaneous felstone (old lava) of Aran Mowddwy,

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* Quart. Journ. Geol. Soc. vol. xxxi. p. 368.

in Wales, we perceive how much more the percentage of phosphoric acid in the latter approaches to that of the granite (No. 6) than to the metamorphosed Cumbrian ashes (Nos. 3 and 4). Of course it would be extremely unwise to conclude that the quantity of phosphoric acid found to occur in the granitic example No. 6 represents the proportion in the granite throughout; what this may be, only a large number of analyses can show.

The only conclusions, therefore, that one is at all warranted in drawing from the above facts are these:—1st. That this thick series of volcanic rocks contains a considerable percentage of phosphoric acid; 2nd. That since there do not occur interstratified sedimentary deposits of an ordinary nature (except *quite* at the base), the phosphoric acid could not have been derived from such rocks *immediately*; 3rd. That, unless derived from the Skiddaw Slates which underlie this thick series of lavas and ashes, the phosphoric acid must probably be considered a special constituent of the volcanic products. The question whether the composition of the Skiddaw Slates is such as to warrant the supposition of the phosphoric acid being derived from them must be deferred to the next part of this memoir, when some analyses of the slate in gradual stages of metamorphism will be brought forward.

If the granite as a mass contain so small a proportion of phosphoric acid as indicated in the single example given, an additional argument may perhaps be derived against the possibility of the granite having been the deep-seated source from which *these particular* volcanic rocks proceeded.

Summary.

1. Both observations in the field, and the examination of a complete series of hand specimens of the altered volcanic rocks of Cumberland, indicate the probability of a passage *from* such rocks *into* granite.
2. The microscopic examination of such a complete series proves the passage from a distinctly fragmentary to a distinctly crystalline rock, and to granite itself.
3. The chemical composition of the bulk of these volcanic rocks (the ash-deposits constituting the bulk) agrees *very closely* with that of the granite.
4. These three points of evidence go far to prove that the granite in this case may consist *in great measure* of but extremely metamorphosed volcanic rocks.
5. This being a possible case (volcanic rocks + metamorphism = granite), it might be argued that granite + communication with the surface = volcanic rocks; the reasons, however, for not considering the granite and volcanic rocks, *in this case,* to have been thus connected have been already brought forward.
6. The metamorphism around, and character of the Shap granite, tend to show that that granitic mass partakes *more* of an intrusive character, though much of the matter of the volcanic rocks immediately surrounding may have been partly incorporated with it, especially near the margins.

7. The volcanic rocks which have as yet been chemically analyzed show a decided increase in the proportion of phosphoric acid on approaching the granite, and a decided decrease in the proportion of carbonic acid.

Appendix.

A full list of all papers bearing on this and other geological questions in the district will be found at the end of the official Survey Memoir on the northern part of the Lake-district; but it will be necessary to mention some of the views of previous authors on the subject of this paper.

Prof. Sedgwick, in his letters on the Geology of the Lake-district, dated 1842, speaks of the zone of altered rocks around the Eskdale granite, "which forms such a passage between the two formations that it is no easy matter to determine the exact boundary-line of either."

Prof. Phillips, in 1858,* alludes to the great series of changes in the volcanic rocks around the granite near Bootle.

Mr. J. G. Marshall, in the same year and in 1861 states† his conviction that the granites and syenites are truly metamorphic, he does not, however, regard the green slates and porphyries as volcanic, but considers that "*the whole series were originally soft stratified deposits.*" In a paper, dated 1868 ‡, Dr. Nicholson draws the following general conclusions—that the Shap granite is of hydro-igneous origin, and that neither it nor the other granites of the district are in any way connected with axes of elevation or disturbance.

EXPLANATION OF PLATE XXXI.

To illustrate the microscopic structure of granitoid rocks, and the passage from altered volcanic rocks to granite.

Fig. 1. Altered ash, with lines of bedding seen in the mass, from south-west of Bell Rib, Yewbarrow, above Wastwater. Magnified 50 times.

2. Altered contemporaneous trap (?), close to the Wastdale Head granite, Lingmell Beck. Magnified 50 times.
3. Represents the same field of view as that seen in fig. 2, but in polarized light, with the prisms crossed. Magnified 50 times.
4. Highly altered ash, close to the Eskdale granite, west of Great How. Magnified 50 times.
5. Bastard granite, traces of bedding in the original ash rock still visible on the weathered exterior, Peers Gill (below Flass Knotts), foot of Scawfell Pikes. Magnified 50 times.
6. Eskdale granite, at the edge, south of Great How. Magnified 50 times.
7. Junction of highly altered ash with Shap granite, Sleddale Pike. Magnified 25 times.

These figures have been copied from coloured drawings made by the author direct from the microscope.

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* "Notice of some phenomena at the junction of the granite and schistose rocks in W. Cumberland," Rep. Brit. Assoc. 1858, Trans. Sects. p. 100.

† "On the Geology of the Lake District, in reference especially to the Metamorphic and Igneous rocks," Brit. Assoc. Rep. for 1858. Trans. Sects. p. 84, and 1861, p. 117.

‡ "On the granite of Shap," Trans. Edin. Geol. Soc. vol. i. p. 133.

Fig. 1.
Polar.

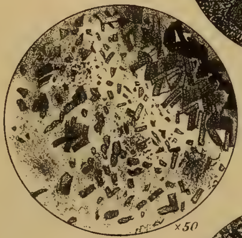


Fig. 2.

Fig. 3.
Polar.

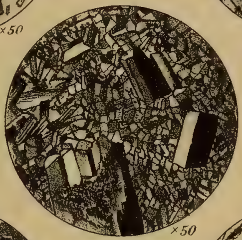


Fig. 4.
Polar.

Fig. 5.
Polar.

Fig. 6.
Polar.

Fig. 7.
Polar.

G.H.Ford.
Mintern Bros. imp.

SECTIONS OF GRANITOID ROCKS OF THE LAKE DISTRICT.

44. *On the* Superficial Geology *of the* Central Region *of* North America. By George M. Dawson, Esq., Assoc. R.S.M., Geologist H.M. North-American Boundary Commission. (Read June 23, 1875.)

(Communicated by Dr. Bigsby, F.R.S., F.G.S.)

[Plate XXXII.]

Physical Geography of the Region.

Where the great region of plain and prairie which occupies the whole central part of Mexico and of the United States crosses the forty-ninth parallel of latitude, which constitutes the political boundary between the last-named country and British North America, it is included in longitude between the 96th and 114th meridians. It narrows pretty rapidly northwards, chiefly by the encroachment on it of its eastern border, but continues as a great physical feature even to the shore of the Arctic ocean, where it appears to have a breadth of between 300 and 400 miles. North of the North Saskatchewan river, however, it loses to a great extent its *prairie* character, and, with the increasing moisture of the climate, becomes thickly covered with coniferous forest.

The eastern boundary of this interior continental plateau, north of latitude forty-nine, is formed by the western slope of that old crystalline nucleus of the continent, which extends north of the St. Lawrence and the great Lakes from Labrador to the Lake of the Woods, with a general east and west course, and then, turning suddenly at an angle of about 60° to its former general direction, runs with a north-north-west course to the Arctic sea. This boundary, though formed, wherever it has been carefully studied, in part of less-metamorphosed rocks generally attributed to the Huronian, may be called the Laurentian axis (see map, Pl. XXXII.) In this part of its course it is not of the nature of a mountain-range. It probably does not attain a height of over 1500 to 2000 feet, and has an average breadth of about 250 miles. It may rather be considered a great rocky plateau; and though it forms the division between the streams running directly into Hudson's Bay and those flowing westward and southward, the actual line of watershed has no determinate direction on it, but follows a devious curve, which in one place (to the east of the region now under consideration) approaches within twenty miles of Lake Superior. Neither is it always a continuous barrier; for near the north end of Lake Winnipeg it is broken through by the Nelson and Churchill rivers, the former of which carries across into Hudson's Bay a great part of the drainage of the plains.

To the west the plateau is bounded by the Rocky Mountains, which rise abruptly from the elevated plain at their base, presenting often to the east almost perpendicular walls of rock. They are composed, not of a single upheaved ridge, but of a number of more or less nearly parallel ranges, which have a general direction a little west of north, and a breadth of over 60 miles, extending from the margin of the great plains to the valleys of the Kootanie and Columbia rivers. In the vicinity of the forty-ninth parallel, the geological continuity of the country is as sharply broken by the line of their eastern base as its physical character, and we pass suddenly from the little-altered or disturbed strata of Cretaceous and Tertiary age to scarped mountain-sides of palæozoic rocks, metamorphosed and crumpled. The higher peaks of the mountains north of the boundary do not seem often to surpass 10,000 feet. The plains may therefore be considered broadly as a trough intervening between the two great longitudinal watersheds of the northern part of the continent. The lowest portion of this trough, however, is several hundred feet above the sea-level; and much of its western part is actually higher than its eastern Laurentian rim (see Section, Pl. XXXII. fig. 2).

Besides the main longitudinal watersheds, there are also two very important transverse ones (see map), which are not marked by any grand physical features, but appear to be merely caused by low gentle rolls in the strata. Of these, one in a general way follows the political boundary of the forty-ninth parallel. It separates the waters of the Red, the Assineboin and Saskatchewan rivers (which find their way through Winnipeg Lake to Hudson's Bay) from those of the Mississippi and Missouri and their various tributaries. Beginning in that region of swamp and lake in Northern Minnesota which feeds the variously destined head-waters of the Winnipeg, St. Lawrence, Mississippi, and Red rivers, it dips southward between the tributaries of the latter two streams, and passes between Lake Traverse and Big-Stone Lake, with an altitude of only 970 feet, about 200 miles south of the boundary-line. Thence it pursues a general north-westerly course along the high lands formed by the southern extensions of Pembina Escarpment and the Missouri Coteau, and, becoming identified with the latter, crosses the boundary-line near the 104th meridian, 300 miles west of Red River. Then falling south of the drift ridge of the Missouri Coteau, it follows the summit of the plateau of the Lignite Tertiary for about 300 miles to the Cyprés Hills, where it is only 40 miles north of the line, in longitude 110° 30′. Thence it trends southward and crosses the forty-ninth parallel for the last time about 30 miles east of the base of the Rocky Mountains. The average altitude of this watershed region east of the Red River is 1400 feet. In Northern Dakota it may be estimated at 2000 feet; and from this it rises till near the mountains it has attained an elevation of about 4000 feet.

The second transverse watershed crosses from the Rocky Mountains to the Laurentian region, near the fifty-fourth parallel; and not much is known about it. It separates the rivers which reach the Arctic Sea directly, from those of the Saskatchewan system, which flow into Hudson's Bay. Where crossed by the canoe-route to Mackenzie River at Methay Portage, near its eastern extremity, its height, according to Sir J. Richardson, is 1566 feet. Near its western extremity it would appear (according to Dr. Hector's observations) to be about 2400 feet. It is probable that this watershed is lower than either of these measurements in the intervening region.

Between the two transverse watersheds thus defined, the three prairie *steppes* or plateaus of different elevation now to be described are embraced.

The whole of the region slopes gradually eastward from the most elevated plains at the base of the Rocky Mountains to the lowest, at the foot of the Laurentian plateau to the east. The inclination becomes more abrupt on approaching the mountains, but not so much as to attract special attention; but along two lines which are in a general way parallel and hold a north-west and south-east course across the plains, a very marked step-like rise occurs. These escarpments form the eastern boundaries of the two higher prairie plateaus. The lowest and most eastern prairie-level is that which includes the valley of the Red River in its southern portion, and northwards embraces Lake Winnipeg and associated lakes and the flat land surrounding them. Its average altitude may be estimated at about 800 feet; its area at 55,600 square miles, of which the great system of lakes in its northern part occupies 13,900 miles; its average width is over 100 miles; its eastern boundary is in part conterminous with the shore of Lake Winnipeg and the Laurentian axis, in part formed by the great drift plateau south of the Lake of the Woods. Its western limit is

Fig. 1.—*View of Pembina Mountain, part of the Escarpment of the Second Prairie-Plateau.*
(From the Alluvial Prairie of the Red River.)

found at the foot of the lowest of the great escarpments already mentioned, which in the vicinity of the boundary-line is known as Pembina Mountain (fig. 1), and, though broken through by the Assineboin river, is continued northward in the Riding, Duck, and Porcupine Mountains.

Rising to the summit of the second prairie-steppe, we find ourselves on the margin of the "Great Plains," properly so called. This plateau has an average elevation of about 1600 feet, and is bounded to the west by the Missouri Coteau and foot of the third prairie-steppe. On the forty-ninth parallel it has a width of 230 miles, on the fifty-fourth of about 200 miles, though it cannot there be so strictly defined. To the south the boundaries of this region appear to become more indefinite, and in the southern part of Dakota the three primary levels of the country, so well marked north of the line, are probably scarcely distinguishable. The elevated region lying south and west of the Lake of the Woods, and forming in one place the eastern boundary of the lowest prairie, also assumes the form of a plateau; and though having an elevation of from 1000 to 1600 feet only, it corresponds with the height which the second plateau above described might be expected to have, had it continued thus far eastward. It is covered to a great depth with drift materials, and may be called the drift plateau of Northern Minnesota.

The third or highest prairie-steppe has an altitude of about 2500 feet where it is first met with; its surface, however, is much less uniform and more weathered than that of the lower plains; and toward the base of the mountains it rises on the boundary-line to a height of 4200 feet, and in the latitude of the North Saskatchewan to about 3000 feet. Southward, as is well known, the plains along the base of the mountains continue to increase in elevation, the level of the passes through the range being equally affected.

The eastern escarpment of this highest steppe (fig. 2) crosses the boundary-line about longitude 103° 30′, and runs thence with a general west-north-west course to the elbow of the South Saskatchewan in longitude 108°. Here it bends abruptly, and, passing due north, crosses the North Saskatchewan river.

Disregarding the two escarpments (which in reality account for but a small part of the westward increase of elevation) and drawing a line in the direction of the greatest general slope of the prairie-surface, from the intersection of the eastern base of the Rocky Mountains and the forty-ninth parallel to a point on the first prairie-level near the northern end of Lake Winnipeg, we find that it crosses the escarpments nearly at right angles, and has an average fall of 5·38 feet per mile. A second line starting at the same point, and terminating eastward in the lowest part of the Red-River valley, on the forty-ninth parallel, shows an inclination of 4·48 feet.

In the foregoing brief summary of the physical features of the region, I have been guided not only by the facts obtained by the Boundary-Commission Surveys, but by the observations of previous explorers, among whom Dr. Hector deserves special mention. To this geologist (who accompanied Capt. Palliser's expedition) is due the first clear definition of the three steppes into which the interior region of British North America is naturally divided.

The region which has come under my own observation is for the most part pretty closely confined to the forty-ninth parallel, and forms a line about 900 miles in length, extending completely across the interior plateau of the continent.

Glacial Phenomena of the Laurentian Axis.

Beginning, then, with the glacial phenomena of the Laurentian axis, I shall describe the appearances presented in the neighbourhood of the Lake of the Woods only, where this axis is intersected by the forty-ninth parallel; but, from the similarity of the traces of glacial action even in very distant parts of the Laurentian region, this will serve in some sense as a representation of its general features.

The Lake of the Woods, as a whole, occupies a depression in the south-western slope of the Laurentian region (see Map, Pl. XXXII.). It is over 70 miles in extreme length, and has a coast-line of between 300 and 400 miles. Its northern part is comparatively deep, reaching in some places a depth of over 80 feet. Its general form has been determined by that of an area of less highly altered rocks, which are probably Huronian; and the details of its outline even follow very closely the changing character of the rock, spreading out over the schistose and thinly cleavable varieties, and becoming narrow and tortuous where compact dioritic rocks, greenstone conglomerate, and gneiss prevail. Its shores are almost invariably composed of solid rock with the rounded forms characteristic of ice-action, and dip rapidly below the surface of the water, forming a bold coast, sandy or gravelly beaches being comparatively rare. It is studded with innumerable islands, few of which are laid down on the imperfect maps yet made of the region, but which vary from those several miles in length to mere water-wasted rocks. The islands, like the mainland, are seen, where not covered with luxuriant vegetation, to be composed of round-backed rocks. Only where the rocks are of a specially soft or schistose character has the action of the waters of the lake had sufficient effect on them to form cliffs. The southern part of the lake is very different: there are few islands; the water is not deep; and the whole southern shore is formed by low-lying deposits of sand and detrital matter, Where rock-surfaces appear, however, they are like those of the northern part of the lake, heavily glaciated.

All the harder rocks of the region still show with the utmost perfection the scratching and grooving of the glacial period; and some of the more compact granites and intrusive diorites retain a surface still perfectly bright and polished. On a small scale even the hardest and most homogeneous of the rocks show a tendency in the longer axis of their elevations to parallelism with the glacial markings. Though the general direction of the northern part of the lake also follows that of the ice-action, it is at the same time that of the belt of Huronian rocks already mentioned. The course of the glacial striæ is extremely uniform, and, from a great number of observations in different parts of the lake, is found to vary through a few points only, lying between north-north-east and south-south-west and north-east and south-west. Slight deflexions, sometimes observed, are generally traceable to deviation of the ice by masses of resistent rock running athwart its course, the striæ always showing a tendency to bend towards the more level regions, and away from the more elevated and rugged parts.

At a few places in the southern part of the lake, glaciation in the ordinary direction which gives form to the rock masses, was observed to be superinscribed with coarser scratches nearly east and west in direction. Some of these may be due to the packing of the ice of the lake itself in the spring; but instances occur which cannot be accounted for in this way. Some rock-surfaces on a low promontory in the southern part of the lake afford interesting examples. The most important direction and that with which the forms of the surface coincide is here S. 13° W., superimposed on which at one place are scratches S. 45° W. or N. 45° E. Near this a direction of S. 50° W. or N. 50° E. occurs, on which is superimposed striation S. 15° W., a direction closely agreeing with the general one, and probably indicating a brief resumption of the original force after a short interval.

Many interesting special cases showing the character and effect of the glacial action, came under observation; but with these I do not wish to burden this paper. The nature of the present outfall of the lake, however, deserves mention. There are two channels now in use, and evidence of at least one other now disused. They cross a narrow ridge which separates the waters of the lake from those of the basin-like head of the Winnipeg River, and are comprised within a distance of about two miles. The hard ridge marks the junction by fault of the Laurentian and Huronian rocks, the line nearly following its crest. The gaps through which the water flows do not depend on any evident peculiarity of geological structure, but probably owe their origin to smaller transverse faults or joints, as a fissure filled with a large greenstone dyke was observed not many miles distant with a direction parallel to theirs. The gorge-like gap through which the northern stream flows is the most interesting, and was most carefully examined. It is occupied by a very picturesque cascade, the first leap of the Winnipeg River. It is certainly preglacial in date, and has probably arisen from subaerial weathering along some line of weakness. The glacial striæ cross over it obliquely at an angle of about 30° with its direction; and the ice has had wonderfully little effect on its shape, having only succeeded in rounding off somewhat the exposed angles of the cliffs. Since the glacial period the river has done little, as the rocks retain their rounded aspects and show ice-striation almost everywhere.

Drift Plateau of Northern Minnesota and Eastern Manitoba.

The great plateau of Northern Minnesota, which stretches southward from the Lake of the Woods, shows only drift materials, and is composed of them to a great depth (see Map and Section Pl. XXXII., *a*). Its general surface is remarkably uniform, and its slopes almost imperceptibly slight. It is, however, diversified on a small scale, being thickly strewn with shallow hollows, which are filled by little lakes or the almost impassable "muskegs" of the region. There are also low flat-topped ridges of sand and gravel of the nature of kames or eskers, and in many localities traces of larger lakes than those now existing, which have been drained by the gradual wearing down of the beds of their outfall streams.

The drift-deposits of this region rest on the gently sloping foot of the Laurentian axis, and are, where I have seen them, composed to a depth of 60 feet or more of fine sands and arenaceous clays, with occasional beds of gravel and small boulders. The finer deposits are generally very evidently false-bedded, and sometimes quite hard. The gravelly layers, as a rule, are found resting on the finer material between it and its surface-soil, and sometimes lie on the denuded edges of the curved sand-beds below. In one place only did I find any trace of organic remains. On the Roseau River, about 30 feet from the top of the bank, a piece of wood protruded from a cliff of hard sandy clay, and, on microscopic examination, appeared to be a fragment of the common cedar (*Thuja occidentalis*). I have no doubt that these distinctly-bedded deposits of the plateau repose throughout on boulder-clay. I have observed them to do so in the southern part of the Lake of the Woods; and, on the Roseau River, also, indications of the underlying boulder-clay are found. In general, however, the few sections which exist do not penetrate sufficiently deep to show this deposit.

An interesting confirmation of the general direction already stated for the glacial action, is found in the composition of the materials of this plateau. Its eastern side, fronting on Lake Superior, is very abrupt, and seems to be held up by a ridge of hard old rocks, which here and there appears from beneath it. Ascending to the plateau-level from the extreme western point of Lake Superior by the Northern Pacific Railway, the drift is seen to have a reddish-purple colour, which continues, though gradually becoming less marked, for some distance after attaining the summit. The colour then changes to the pale yellowish grey which is generally characteristic of the drift of this plateau. The red drift is derived from the red rocks of the border of the lake, and is found along its whole southern side. It is here bounded by a line lying a short distance back from the north-western shore and nearly parallel to it. This western edge of the red drift has been already noticed by Whittlesey in his paper in the Smithsonian Contributions. The surface of the plateau is very generally strewn with erratics; and some of them are of great size. They are chiefly derived from the Laurentian and Huronian to the north; but there are also many of white limestone. Dr. Bigsby has given an account of the geology of the Lake of the Woods and of the distribution and origin of the erratics there, in former volumes of the Journal of this Society (Quart. Journ. Geol. Soc. 1851 and 1852.) Its shores and islands are covered with boulders, most of which can be traced to outcrops of similar rocks not far to the north-east; but here too a considerable quantity of limestone is found. It is not generally in such large fragments as the metamorphic rocks, and is often seen in small pebbles only, but occurs in some places in great profusion. The limestone drift is entirely confined to the southern and western shores of the lake; and its origin is a question of some difficulty. No similar rock is known to exist to the north-east, unless the limestones of the shores of Hudson's Bay are of this character. Limestone is known to occur on the western side of the Laurentian axis 50 miles further north-west, and beyond that point in great abundance. The limestone there found, however, is of Lower Silurian and Devonian age, while the fossils in some, at least, of the erratics prove them to be Upper Silurian. A south-eastern drift of floating ice may account for some of the specimens; but I am inclined to believe, with Dr. Bigsby, that an outcrop of Upper Silurian is concealed by the drift-deposits along the base of the Laurentian in the Lake-of-the-Woods region.

Lowest Prairie-Level and Valley of the Red River.

Descending the western side of the drift plateau of Northern Minnesota, we enter the valley of the Red River (Pl. XXXII., *b*); by which term I mean to express not the whole drainage-area of the stream in a strict geographical sense, but the well-defined and comparatively narrow trough holding the main stream, and here constituting the first prairie-level, which is bounded westward by the front of the second prairie-steppe. This trough runs nearly due north and south, and, from the south shore of Lake Winnipeg to the source of the Red River in Lake Traverse, is 315 miles in length. It does not end here, however, but passes by a continuous gap, never more than 690 feet above the sea-level, to the source of the Minnesota River, a tributary of the Mississippi. On the boundary-line the valley is 46 miles wide, and it narrows very gradually southwards. The floor of the valley, though it slopes upwards towards the sides, does so at so small an angle as to be quite imperceptible to the eye. It presents an appearance of perfect horizontality, and is perhaps the most absolutely level prairie-region of America. Looking down, towards evening, through one of the breaches in the edge of the western escarpment, it requires little imagination to suppose that the bluish level expanse is that of the sea; and, indeed, the whole of this valley must, at a time geologically modern, have been occupied by a great lake, the fine silty deposits of which now form its level floor. On examining these deposits they are found to be arranged in thin horizontal beds, which together constitute a great thickness, and rest upon till or boulder-clay. Some of the layers immediately overlying the till may correspond with those already described in the same relative position on the drift plateau; but I believe that nearly the whole thickness of the horizontal deposit belongs to the great lake of a later period. Stones of any kind are very seldom found on this prairie; they are so rare, indeed, that those which I have seen during all my excursions over it probably do not exceed twenty in number. They have no doubt been brought to their present position by the shore-ice of the lake itself, and are similar to those associated with the drift-deposits of its bounding escarpments.

Ascending the front of the western escarpment, it is found, as might almost have been foreseen, to be terraced; and on leaving the alluvial flat, boulders are again found abundantly, both strewing the terraces and the summit of the "mountain" or second prairie-steppe. The terraces not only occur on the front of this escarpment, but extend westward along the banks of the great valley of Pembina River, which at the time of their formation must have been an inlet of the lake, and is therefore probably of preglacial age.

Second Prairie-Plateau.

The surface of the second plateau or steppe of the plain (Pl. XXXII., *c*) appears to be almost everywhere very thickly covered with drift deposits; and the undulations and slight irregularities of its contour seem in the main due to the arrangement of these surface-materials, which, though no doubt somewhat modified by subsequent denudation, do not seem to have suffered much. Over large areas no systems of "coulées" or stream-valleys are to be found; and the generally undulated surface must be due to original inequality of deposition, though a certain quantity of material has no doubt been removed from the rounded hillocks into the intervening basin-like swamps and hollows. Such an arrangement not only implies the porous nature of the subsoil, but is in accordance with the comparatively very small rainfall of the region, and would tend to show that at no time since its emergence has the precipitation been great. It was observed that in many places boulders and gravel are equally abundant on the crests of the gentle ridges and hillocks and in the hollows, while they are comparatively seldom seen on the intervening slopes. A similar observation has been made by Prof. Bell in a part of the second steppe considerably further north, and would tend to show slight erosion of the surface by marine currents subsequent to the deposition of the heavier materials.

The drift material is found generally to consist in great part of local débris derived from the immediately underlying soft formations; but this is always mixed with a considerable quantity of far-transported material, which is generally most abundant in the upper layers. Large erratics are in some localities very plentifully strewn over the plains, but they seem to be almost always superficial. They are generally of Laurentian rocks; but whitish and yellowish limestone, derived from the Silurian flanking the western base of the Laurentian region, is abundant. A bank in Long-River Valley shows in an interesting section, about 30 feet of drift, resting on

Cretaceous clay or shale. Of the drift the lower portion is composed of stratified sands and gravels, which are evidently false-bedded. The pebbles are chiefly of the underlying rock, which, though soon splitting up under subaerial influences, has been hard enough to bear rounding under water. There are also a few samples of rocks of foreign origin, and the whole arranged in a manner implying a very strong flow of currents in different directions. About 11 feet from the top of the bank the false-bedded layers end abruptly, being cut off by a well-marked horizontal plane. Above this the bedding is nearly horizontal, and the drift includes many travelled boulders of Laurentian and white limestone, some of them large, together with much small Cretaceous stuff. Large boulders are also abundant, protruding from the surface of the prairie above.

In other places similar hard yellowish sandy clays are met with, but with little sign of stratification, holding many well glaciated stones, and thus resembling true till or boulder-clay. I do not think that the boulder-clay and more perfectly stratified materials are here essentially distinct; but, as they were never seen in the same section, I cannot speak positively on this point. In order to ascertain as far as possible the origin of the foreign material of the drift and the relative proportions of the different constituents, I adopted the following method:—An average collection of pebbles taken at random from the gravel of any locality was made, stones above or below a certain size being rejected for convenience, and care being taken, where possible, to combine gatherings from two or three spots for each locality, and to make the collection a large one. The pebbles so obtained were then carefully enumerated and divided lithologically into groups, which were referred as far as possible to their formations. From the numbers thus obtained percentage ratios have been calculated. The comparative simplicity of the geological features of the interior of the continent, the similarity of the lithological characters of the formations over great areas, and the absence of harder metamorphic rocks in the strata of the plains are specially favourable to such an investigation; and the results serve to show the general course of the drift in a region where rock-surfaces capable of preserving glacial striæ are entirely absent. It was at first intended to enumerate the boulders and larger erratics in this way; but the criterion of smaller pebbles was found more frequently applicable; and wherever comparison was possible, the result obtained from them appeared to agree closely with the proportional importance of the larger masses. I shall present here only the general average deduced from the second prairie-steppe as a whole, which is as follows:—

Laurentian	28·49
Huronian	9·71
Limestone	54·01
Quartzite Drift	1·14

The Laurentian material, consisting of granites and gneisses, is easily distinguishable. Those classed as Huronian are chiefly hard, greenish, epidotic, and hornblendic altered rocks. It is interesting to observe that the proportional importance of the Laurentian and Huronian, thus ascertained for the drift, is nearly that of their areas where they have been mapped. The proportions in the drift are respectively three to one. Prof. Bell, of the Geological Survey, has stated the proportion by area of Laurentian and Huronian in the region north-west of Lake Superior as two to one, leaving a slight preponderance of the former over the latter in the drift, as compared with the areas in the metamorphic axis, which arises no doubt from the greater prominence of the harder Laurentian rocks. The limestone is that of the flanks of the Laurentian axis; and its great abundance is an interesting feature, and one tending to prove that this rock must in preglacial times have lapped far up on the Laurentian. These three classes are derived from the north-east or east. The fourth or *Quartzite drift* is a general name which I have applied to that coming from the Rocky Mountains, which, although not entirely composed of quartzite, is characterized by the great abundance of that material, and has a peculiar and distinctive appearance. This drift was met with abundantly in many places further west; but it was only in August last that I was able to trace it to its origin in the mountains. It occurs, as will be noticed, very sparingly on this second prairie-level, and is not found over its whole area. The first clearly recognizable fragments were met with near the 101st meridian, 580 miles from the Rocky Mountains, and over 200 from the nearest part of the Laurentian region.

On the surface of this prairie-level there occur some remarkable elevated regions, which seem to be entirely composed of accumulated drift materials (see Map, Pl. XXXII.). The most prominent of these are included under the names of Turtle Mountain, Moose Mountain, and the Touchwood Hills. Though quite unconnected, these elevations follow in a general way a contour-line of the surface, and form a range roughly parallel to the Coteau, to which in their appearance and material they also bear the closest likeness. Of these elevations the only one which I have personally examined is that known as Turtle Mountain, which is bisected by the forty-ninth parallel and forms the most southern of the series. It is a region of broken hilly ground, which may be about 20 miles square, and is for the most part thickly wooded—a circumstance which renders it a specially prominent feature when viewed across the prairie. Its extreme height is not more than 500 feet above the prairie at its base; and its general elevation is a little more than 2000 feet above the sea, or nearly the same as that of the surface of the Coteau. On approaching it from the east the already gently-swelling plain becomes more markedly undulating, small basin-like swamps and ponds are more frequent, and its junction with the region of the "Mountain" would be undefinable but for the limiting border of the woods. The western end of the mountain is more abrupt towards the plain, and is much diversified with ridges, between which lie swamps and lakes, which show a general tendency to arrangement in north-and-south lines. Towards the eastern end there are somewhat extensive areas of gently undulating land, though always characterized by the abundance of pools and swamps. Notwithstanding the apparent abundance of water, there are few brooks or drainage-valleys, and the streams which do occur are quite small. The surface seems very nearly that of the drift as originally deposited, though sufficient fine material has been washed from the ridges to render the intervening hollows flat-bottomed.

Edge of the Third Prairie-Plateau.

One hundred and twenty miles west of Turtle Mountain the second prairie-plateau comes to an end against the foot of the great belt of drift deposits known as the Missouri Coteau. Beyond this point three diverse zones of country cross the forty-ninth parallel obliquely with a west-north-west course, in the order subjoined:—

1. Tumultuously hilly country based on a great thickness of drift, and forming the Coteau de Missouri properly so called.
2. Flat-topped *watershed plateau*, formed of rocks of the Lignite Tertiary, and constituting a part of the first transverse watershed already described.
3. Lower, broken-down region, south of the plateau, partly based on the Lignite Tertiary, and characterized by gorges and large valleys draining towards the Missouri.

The second region can perhaps hardly be said to cross the line, but appears immediately north of it. On the line and southward the streams flowing to the Missouri rise near the southern edge of the first division, the greater part of the plateau having succumbed to denuding agencies.

The Missouri Coteau (fig. 2, and Map and section Pl. XXXII., *z*) is one of the most important features of the western plains, and is certainly the most remarkable monument of the Glacial period now existing there. I have had the opportunity of examining more or less carefully that portion of it which crosses the forty-ninth parallel, north-westward for a length of about 100 miles. On the parallel, the breadth of the Coteau, measured at right angles to its general course, is about 30 miles; and it widens somewhat northward.

On approaching its base, which is always well defined at a distance, a gradual ascent is made, amounting in a distance of 25 miles to over 150 feet. The surface at the same time becomes more markedly undulating, as on nearing Turtle Mountain from the east, till, almost before one is aware of the change, the trail is winding among a confusion of abruptly rounded and tumultuous hills. They consist entirely of drift material; and many of them seem to be formed almost altogether of boulders and gravel, the finer matter having been to a great extent washed down into the hollows and basin-like valleys without outlets with which this district abounds. The ridges and valleys have in general no very determined direction; but a slight tendency to arrangement in north-and-south lines was observable in some places.

The boulders and gravel of the Coteau are chiefly of Laurentian origin, with, however, a good deal of the usual white limestone and a slight admixture of the quartzite drift. The whole of the Coteau-belt is characterized by the absence of drainage-valleys; and in consequence its pools and lakes are often charged with salts, of which sulphates of soda and magnesia are the most abundant. The saline lakes frequently dry up completely towards the end of the summer, and present wide expanses of white efflorescent crystals, which contrast in colour with the crimson *Salicornia* with which they are often fringed.

Taking the difference of level between the last Tertiary rocks seen near the eastern base of the Coteau, and those first found on its western side, a distance of about 70 miles, we find a rise of 600 feet. The slope of the surface of the underlying rocks is therefore, assuming it to be uniform, a little less than 100 feet per mile. On and against this gently inclined plane the immense drift deposits of the Coteau hills are piled.

The average elevation of the Coteau above the sea, near the forty-ninth parallel, is about 2000 feet; and few of the hills rise more than 100 feet above the general level.

Between the south-western side of the Coteau belt and the Tertiary plateau is a very interesting region with characters of its own. Wide and deep valleys with systems of tributary coulées have been cut in the soft rocks of the northern foot of the plateau, some of which have small streams still flowing in them fed by its drainage; but for the most part they are dry, or occupied by chains of small saline lakes which dry up early in the summer. Some large and deep saline lakes also exist which do not disappear even late in the autumn. They have a winding, river-like form, and fill steep-sided valleys. These great old valleys have now no outlet; they are evidently of preglacial age, and have formed a part of the former sculpture of the country. The heaping of the great mass of débris of the Coteau against the

Fig. 2.—*The Missouri Coteau, forming the edge of the Third Prairie.* Long. 104° W. (From the north-east, distant about 4 miles.)

foot of the Tertiary plateau has blocked them up and prevented the waters finding their way northward as before; and since glacial times the rainfall of the district has never been sufficiently great in proportion to the evaporation to enable the streams to cut through the barrier thus formed. The existence of these old valleys, and the arrangement of the drift-deposits with regard to them, throw important light on the former history of the plains.

Northward, the Coteau ceases to be identified with the Tertiary plateau, and rests on a slope of Cretaceous rocks. It can be followed by Palliser's and Hector's descriptions of the country to the elbow of the South Saskatchewan, and thence in a line nearly due north through the Eagle and Thickwood Hills; beyond the North Saskatchewan, however, it appears to become more broken and less definite. In Dr. Hector's description of certain great valleys without outlet in this northern region, I believe I can recognize there too the existence of old blocked-up river-courses similar to those just described.

South of the forty-ninth parallel the continuation of the belt of drift material can also be traced. It runs south-eastward, characterizing the high ground between the tributaries of the Missouri and the Red River, which has already been noticed in connexion with the watershed of the continent; but wanting the backing of the Lignite-Tertiary plateau, it appears to become more diffuse, and spread more widely over the country. That the drift-deposits do not *form* the high ground of the watershed, but are merely piled upon it, is evident, as Cretaceous rocks are frequently seen in its neighbourhood at no great depth. From what I can learn of the region it would appear that the so-called Coteau des Prairies and Coteau de Missouri, between which a distinction is made on the maps, are parts of the same great feature. Their elevation is similar, and nearly the same as that of the Coteau on the line; and they are equally characterized by the immense profusion of erratics with which they are strewn, and by basin-like swamps and lakes. The Coteau des Prairies, however, stretches furthest, and dies away only in the south-western corner of Minnesota.

In the Coteau, then, we have a natural feature of the first magnitude—a mass of glacial débris and travelled blocks with an average breadth of perhaps 30 to 40 miles, and extending diagonally across the central region of the continent for a distance of about 800 miles.

Third or Highest Prairie-Plateau.

Passing the Coteau and ascending the plateau of the Tertiary (Pl. XXXII., *d*), we notice at once a change in the character of the drift deposits. They are much thinner, and, area for area, perhaps do not equal one twentieth of those on the second prairie-steppe. They are also now largely composed of *quartzite drift* from the Rocky Mountains, of the nature of shingle, and seldom showing much trace of glaciation. With this western drift, however, a smaller proportion of that from the east or north-east is mingled. South of the watershed-plateau the third region (that sloping to the Missouri, where it is well sheltered to the north) shows the *quartzite drift* in even greater purity. Where, however, gaps or lower places in the watershed-plateau occur, incursions of Laurentian rocks and of eastern limestones are also found to a greater or less extent.

The general character of the travelled drift of the third steppe may be seen from its percentage composition, derived in the same way as already shown for the second steppe.

Laurentian	27·05
Huronian	?
Limestone	15·84
Quartzite Drift	52·10

Though the percentage of Laurentian material appears nearly the same as before, the much smaller total quantity of drift on this level must be remembered. A mark of interrogation is put after Huronian, to indicate that a few specimens of this formation may be present, but, if so, are undistinguishable from some varieties of the *Quartzite drift.* The great decrease in limestone is at once seen; and even the percentage here given includes some specimens of Rocky-Mountain limestone which has travelled eastward with the *Quartzite drift.* The limestones of the flanks of the Laurentian were probably completely submerged ere the water reached the level of the third steppe. Quartzite and similar rocks now form over half of the entire travelled portion of the drift deposit.

Some of the lower parts of this steppe show thick deposits of true till or boulder-clay, which holds in a hard yellowish sandy matrix well glaciated stones, both from the mountains and from the east, and also a great quantity of débris from the softer underlying beds, among which are fragments of lignite from the Tertiary. These deposits of till, though generally massive and weathering into rudely columnar forms in perpendicular banks, often show traces of bedding and arrangement in water; and false-bedded sandy masses are found abruptly cut off above the confused bouldery clay. The shingle deposits of the higher levels may perhaps be formed partly from the rearrangement of this material; they are at least superior to it.

The width of the third steppe, on the line, is about 450 miles; but it narrows rapidly northward. Its surface is more diversified and worn than that of either of the other prairie-levels; and the occurrence and features of the drift are less constant. Following it westward, and in the main slowly rising, Laurentian and Eastern limestone boulders continue to occur to within about 25 miles of the base of the Rocky Mountains, at a height of about 4200 feet. The distance of these travelled blocks from the nearest part of the Laurentian region is over 700 miles. Beyond this point eastern and northern rocks were not found: but that the depression of the continent ceased here cannot be argued from this fact; for by this time the whole of the Laurentian highlands would be submerged.

On the higher prairie, sloping up towards the mountains, the drift is entirely composed of material derived from them, and consists of quartzite, with softer shaly and slaty rocks, and limestone, which is generally distinguishable from that of eastern origin. No granitic or gneissic rocks occur in the vicinity of the forty-ninth parallel, or northwards in British America, in the eastern ranges, so far as is known. Southwards, in Montana, granites and gneisses are found underlying all the other formations, but they do not appear to be very extensively exposed.

The Rocky Mountains.

The brook issuing eastward from the mouth of the South Kootanie Pass has cut through a great thickness of clean gravel drift, composed of large and uniform well-rounded pebbles. Above the brook, on the flanks of the mountains on the south side, are several well-preserved terrace-levels composed of similar material. The highest of of these, though its altitude was not actually measured, was estimated from the known altitude of the Pass to be about 4400 feet above the sea. From the position of these terraces, in the open eastern throat of the pass, from which the whole surface of the country falls rapidly away, they can hardly be other than old sea-marks. The topography of the region would not allow me to explain them on any hypothesis of a former moraine blocking up the valley.

Dr. Hector has measured similar terraces at several points along the Rocky Mountains north of the region now more especially under consideration, and states that they may be said to range from 3500 to 4500 feet above the sea. He also states that in the region examined by him the ordinary Laurentian erratics were not observed above 3000 feet, but mentions a very remarkable line of boulders of red granite deposited on the plains at a height of 3700 feet, which, knowing what we now do of the country, can hardly be supposed to have other origin than the Laurentian axis. It will be observed that my measurements tally closely with Dr. Hector's for the more northern part of the region.

Among the Rocky Mountains themselves traces of the former action of glaciers are everywhere abundant, though in the part of the range near the forty-ninth parallel glaciers do not at present exist. The evidence here met with so closely resembles that found in many other mountain-regions as to render it unnecessary that it should be gone over in detail. Nearly all the valleys hold remnants of moraines, some of them still very perfect. The harder rocks show the usual rounded forms; but striation was only observed in a single locality, and there coincided exactly with the main direction of the valley.

The valleys radiating from the summits of greatest elevation hold long lakes, many of which appear to be deep, and are filled with the most pellucid water. Whether they are in all cases dammed in by moraine matter I was unable to determine. These longer valleys very generally terminate in *cirques*, or amphitheatres, with almost perpendicular back and sides, which overlook small but deep terminal lakelets, held in by moraine-matter and shattered rock.

In these sheltered hollows, and on the shady sides of the higher peaks, are masses of perennial snow, which have no doubt kept up the direct succession from the time when great *névés* filled the heads of the valleys and the mountains around them were completely snow-clad, and are only waiting some change in the climatic conditions, to advance again down the old valleys and occupy the places they formerly filled.

State of the Interior Region of the Continent previous to the Glacial Period.

Having briefly stated the main phenomena of the Glacial period in the central region of North America, it may be well to recapitulate and to give some of the conclusions to which I have been led by their study.

Before the onset of glacial conditions we find the continent standing at least at its present elevation, with its complete system of drainage from the larger river-valleys to many of their less important tributaries already outlined. Subaerial action must before this time have been in operation for a vast period, all the great features of the western plains having been already marked out, and the removal of a truly enormous mass of the soft and nearly horizontal Tertiary and Cretaceous rocks effected. That some very considerable changes in the direction of the drainage of the country in preglacial and in modern times took place, however, is probable. An examination of the Lake-of-the-Woods region and a comparison of levels render it almost certain that the waters of the area now drained by its tributary streams then found their outlet southward and westward, towards the present valley of the Red River, and that only after the blocking up of the southern region with the deposits of the drift did the waters flow over the preexisting breach in the northern rim of the lake, and descend over the surface of the Laurentian to Lake Winnipeg. The Winnipeg River does not show any of the characters of a true river-valley, but consists of eroded and glaciated rock-hollows, from one to another of which the stream falls. There is also some evidence to show that the Red River itself, agreeing with the general structure of the country, flowed southwards; and if so, the Saskatchewan, too, would probably with it join the former representative of the Mississippi.

This subject, however, requires a more detailed discussion than can be granted it in this place.

Mode of Glaciation and Formation of the Drift Deposits.

To the precise manner in which the Glacial period was initiated, the area now in question gives no clue; but I have not found, either in the Laurentian region, or over the area of the plains, or in the Rocky Mountains, any evidence necessitating the supposition of a great northern ice-cap or its southward progress.

The great drift ridge of the Missouri Coteau at first sight resembles a gigantic glacier-moraine; and, marking its course in the map, it might be argued that the nearly parallel line of elevations, of which Turtle Mountain forms one, are remnants of a second line of moraine produced as a feebler effort by the retiring ice-sheet.

Such a glacier must either have been the southern extension of a polar ice-cap, or derived from the elevated Laurentian region to the east and north; but I think, in view of the physical features of the country, neither of these theories can be sustained.

To reach the country in the vicinity of the forty-ninth parallel a northern ice-sheet would have to move up the long slope from the Arctic Ocean and cross the second transverse watershed, then, after descending to the level of the Saskatchewan valley, again to ascend the slope (amounting, as has been shown, to over 4 feet per mile) to the first transverse watershed and plateau of the Lignite Tertiary. Such an ice-sheet, moving throughout on broad plains of soft, unconsolidated Cretaceous and Tertiary rocks, would be expected to mark the surface with broad flutings parallel to its direction, and to obliterate the transverse watersheds and valleys.

If it be supposed that a huge glacier resting on the Laurentian axis spread westward across the plains, the physical difficulties are even more serious. The ice moving southward, after having descended into the Red-River trough, would have had to ascend the eastern escarpment of soft Cretaceous rocks forming its western side, which in one place rises over 900 feet above it. Having gained the second prairie-steppe, it would have had to pass westward up its sloping surface, surmount the soft edge of the third steppe without much altering its form, and finally terminate over 700 miles from its source, and at a height exceeding the present elevation of the Laurentian axis by over 2000 feet. The distribution of the drift equally negatives either of these theories, which would suppose the passage of an immense glacier across the plains.

In attributing the glacial phenomena of the great plain to the action of floating ice, I find myself in accord with Dr. Hector, who has studied a great part of the basin of the Saskatchewan—and also, so far as I can judge from his reports, with Dr. Hayden, who, more than any other geologist, has had the opportunity of becoming familiar with all parts of the Western States.

The glaciating agent of the Laurentian plateau in the Lake-of-the-Woods region, however, cannot have been other than glacier-ice. The rounding, striation, and polishing of the rocks there, are glacier-work; and icebergs floating, with however steady a current, cannot be supposed to have passed over the higher region of the watershed to the north, and then, following the direction of the striæ and gaining ever deeper water, to have borne down on the subjacent rocks. The slope of the axis, however, is too small to account for the spontaneous descent of ordinary glaciers. In a distance of about 30 miles, in the vicinity of the Lake of the Woods, the fall of the general surface of the country is only about 3½ feet to the mile. The height of the watershed-region north-east of the lake has not been actually measured; but near Lac Seul, which closely corresponds with the direction required by glaciation, according to Mr. Selwyn's measurements it cannot be over 1400 feet. The height of land in other parts of the Laurentian region is very uniformly between about 1600 and 1200 feet. Allowing, then, 1600 feet as a maximum for the region north-east of the Lake of the Woods, and taking into account the height of that lake and the distance, the general slope is not greater than about 3 feet per mile—an estimate agreeing closely with the last, which is for a smaller area and obtained in a different way. This slope cannot be considered sufficient to impel a glacier over a rocky surface which Sir William Logan has well characterized as "mamillated," unless the glacier be a confluent one pressed outwards mainly by its own weight and mass.

Such a glacier, I conceive, must have occupied the Laurentian highlands; and from its wall-like front were detached the icebergs which strewed ths débris over the then submerged plains, and gave rise to the various monuments of its action now found there.

The sea, or a body of water in communication with it, which may have been during the first stages of the depression partly or almost entirely fresh, crept slowly upward and spread westward across the plains, carrying with it icebergs from the east and north. During its progress most of the features of the glacial deposits were impressed. In the section described at Long River we find evidence of shallow current-deposited banks of local material, afterwards, with deepening water, planed off by heavy ice depositing travelled boulders.

The sea reaching the edge of the slope constituting the front of the highest prairie-level, the deposition of the Coteau began, and must have kept pace with the increasing depth of the water and prevented the action of heavy ice on the front of the Tertiary plateau. The water may also have been too much encumbered with ice to allow the formation of heavy waves.

The isolated drift highlands of the second plateau, including the Touchwood Hills, Moose Mountain and Turtle Mountain, must also at this time have been formed. With regard to the two former, I do not know whether there is any preglacial nucleus round which drift-bearing icebergs may have gathered. There is no reason to suppose that Turtle Mountain had any such predisposing cause; but it would appear that a shoal once formed, by currents or otherwise, must have been perpetuated and built up in an increasing ratio by the grounding of the floating ice.

The Rocky Mountains were probably also at this time covered with descending glaciers; but these would appear to have been smaller than those of the Laurentian axis, as might, indeed, be presupposed from their position and comparatively small gathering-surface. The sea, when it reached their base, received from them smaller icebergs; and by these and the shore-ice the *quartzite-drift* deposits appear to have been spread. That this material should have travelled in an opposite direction to the greater mass of the drift is not strange; for while the larger eastern and northern icebergs may have moved with the deeper currents, the smaller western ice may have taken directions caused by surface-currents from the south and west, or even been impelled by the prevailing winds. Some of the Laurentian débris, as we have seen, reached almost to the mountains, while some of the *quartzite drift* can be distinguished far out towards the Laurentian axis.

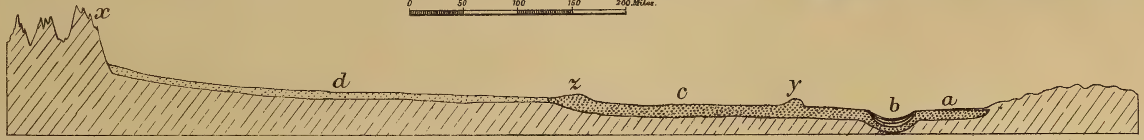
The occurrence of Laurentian fragments at a stage in the subsidence when, making every allowance for subsequent degradation, the Laurentian axis must have been far below water, would tend to show that the weight and mass of the ice-cap was such as to enable it to remain as a glacier till submergence was very deep.

The emergence of the land would seem to have been more rapid; or at least I do not find any phenomena requiring long action at this period. The water in retreat must have rearranged to some extent a part of the surface-materials. The quartzite drift of the third steppe was probably more uniformly spread at this time, and a part of the surface-sculpture of the drift-deposits of the second plateau may have been produced. It seems certain, however, that the Rocky Mountains still held comparatively small glaciers, and that the Laurentian region on its emergence was again clad to some extent with ice, for at least a short time. The closing episode of the Glacial period in this region was the formation of the great freshwater lake of the Red-River valley, or first prairie-level (which was only gradually drained), and the reexcavation of the river-courses.

It must not be concealed that there are difficulties yet unaccounted for by the theory of the glaciation and deposit of drift on the plains by icebergs; and chief among these is the absence, wherever I have examined the deposits and elsewhere over the West, of the remains of marine Mollusca or other forms of marine life. With a submergence as great as that necessitated by the facts it is impossible to explain the exclusion of the sea; for, besides the evidence of the higher western plains and Rocky Mountains, there are terraces between the Lake of the Woods and Lake Superior nearly to the summit of the Laurentian axis, and corresponding beach-marks on the face of the northern part of the second prairie escarpment.

Mr. Belt, in an interesting paper (Quart. Journ. Geol. Soc. Nov. 1874), deals with similar difficulties in explaining the glaciation of Siberia. The northern part of Asia appears in many ways to resemble that of America; surrounded by mountain-chains on all sides save the north, it is a sort of interior continental basin covered with "vast level sheets of sand and loam." As in the interior regions of America, marine shells are absent, or are only found along the low ground of the northern coast. To account for these facts, Mr. Belt resorts to a theory first suggested by him eight years ago, by which he supposes the existence of a polar ice-sheet capable of blocking up the entire northern front of the country, and damming back its waters to form an immense freshwater lake. The outfall of this lake, during its highest stage, he supposes to have been through the depression between the southern termination of the Ourals and the western end of the Altai to the Aral and Caspian Seas.

Fig. 2.



G.H.Ford.

Mintern Bros. imp.

MAP AND SECTION OF PART OF THE INTERIOR OF NORTH AMERICA.

Prof. N. H. Winchell, in an article in the 'Popular Science Monthly' for June 1873, entitled "The Drift Deposits of the North-west," broadly accounts for the glacial phenomena on the supposition of a polar glacier. His illustrations are chiefly borrowed from a careful study of the region south of the Great Lakes of the St. Laurence; but as he includes the Valley of the Red River and the entire North-west in his deductions, a brief note may not be inappropriate. The most suggestive portion of the paper is that in which, like Mr. Belt, he traces the necessary production of a great inland lake or sea of fresh water while the foot of such an ice-sheet as that supposed gradually retreats towards the north, down the gentle inclined plane of the surface of the country. In this manner the finer stratified deposits of certain regions south of the Great Lakes are accounted for, and also those of the great valley south of Lake Winnipeg.

Ingenious as this hypothesis of a great glacial lake undoubtedly is, its inapplicability to the phenomena and physical features presented by the region under consideration is at once apparent. In addition to what has already been said, I need perhaps mention but one additional circumstance which appears discordant with it.

From the physical geography of the region it will be evident that the entire drainage of the supposed immense lake must have passed southward by the Red-River valley. There is here no range of mountains to be crossed; and no reason can be assigned why a channel once formed should not have been cut down through the gentle swell of the watershed and remained the permanent, as it appears to have been the primitive, exit of the drainage of the country.

The whole question is a very interesting one; and it would seem probable that the solution once arrived at will be found to apply equally to Northern America and Northern Asia.

EXPLANATION OF PLATE XXXII.

Fig. 1. Map of part of the interior region of North America, showing the watersheds and three primary levels of the plains, the general character of the drift, and the Missouri Coteau. *a.* The Drift plateau of Northern Minnesota, with drift chiefly of northern and north-eastern origin. *b.* Lowest prairie-level and valley of the Red River. *c.* Second prairie-plateau, drift derived chiefly from the east and north-east. *d.* Third or highest prairie-plateau, drift chiefly composed of quartzite from the Rocky Mountains, *x.* *z.* Missouri Coteau.

2. General section along the 49th parallel from the Rocky Mountains to the Laurentian axis. Vertical scale much exaggerated. *a, b, c, d x,* and *z* as in fig. 1. *y.* Turtle Mountain.

45. *On the* STRUCTURE *of the* SKULL *of* RHIZODUS.

By L. C. MIALL, Esq. (Read June 9, 1875.)

MUCH yet remains to be known of the carboniferous genus *Rhizodus*, of which only the teeth, scales, pectoral arch, jugular plates and mandible have hitherto been identified.

A large and tolerably perfect skull in the Woodwardian Museum at Cambridge affords an opportunity of a more extended notice than has hitherto been possible. The fossil is derived from coal-shale at Gilmerton, near Edinburgh. The skull itself is largely infiltrated with carbonate of iron. In its present slightly disturbed state it measures about 10 inches by 8 inches. The left orbit and the left nasal foramen are capable of identification. Two teeth are seen. They present the double cutting-edge and the folded base characteristic of the genus *Rhizodus*, and differ in no respect from the teeth of *R. Hibberti*, Ag. The rami of the mandible have been pressed upwards, so as to conceal the maxillary region. The exposed surface of all the bones is covered with a well-defined, coarsely granular sculpture, consisting of ridges and tubercles separated by grooves and pits. Many fractures are apparent; and the original surface is in some places removed; so that the delineation of the sutures is often a matter of difficulty. The membrane bones which roof-in the skulls of fishes are so extremely variable, especially in the lateral and posterior tracts, that their homology is often most obscure. In this notice the nomenclature of Prof. Huxley's essay on the Systematic Arrangement of the Fishes of the Devonian Epoch * has been employed.

The fore part of the skull in its present state shows an unpaired ossification corresponding to the ethmoid of *Polypterus*, *Megalichthys*, and other Ganoid fishes (*Eth.* in fig.). This is bounded behind by a nearly straight transverse suture, with a short median process directed backwards between the anterior ends of the frontal bones. A nasal foramen (*Ne*), small and apparently round, lies on the left side of the ethmoid, in the angle between it and what is apparently the anterior end of the maxilla. The præmaxillæ are entirely obscured by the mandible. Behind the ethmoid, in the middle line, is a pair of ossifications, which appear to represent the frontals (*Fr*). They are small, somewhat unsymmetrical, perhaps owing to distortion, and broader in front than behind. External to these, on the left side of the skull, one of the orbits (*Orb*) can be distinguished. Its borders are fractured; and a mandibular tooth, with the point upwards, lies in it. The cavity appears to have been very small, and of irregular figure, as in *Megalichthys*. A pair of large parietals (*Pa*) succeed. The posterior boundaries of these cannot be defined. External to the parietals there are, as in *Megalichthys*, a pair of ossifications, which cannot be certainly identified. The occipital region is very obscure, and disfigured by a wide central crack. The postero-lateral ossifi-

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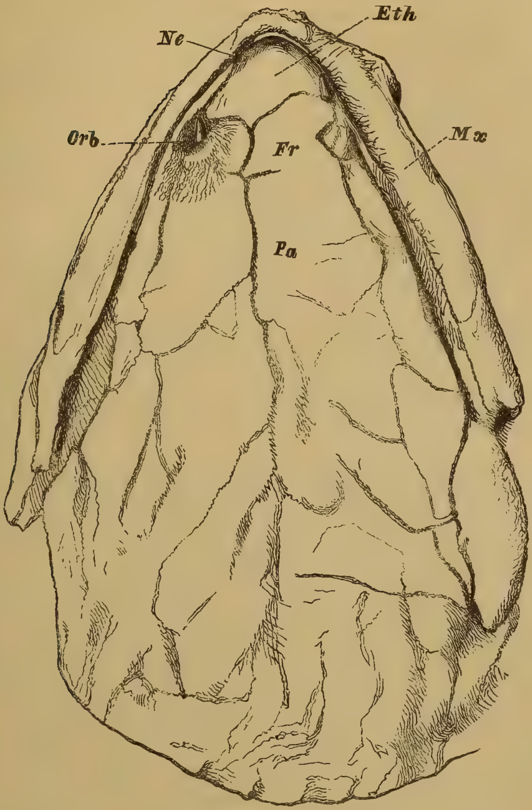
* Mem. Geol. Survey, Decade x. (1861).

Skull of Rhizodus ($\frac{4}{10}$ nat. size).



cations cannot be clearly defined, with the exception of the opercular bone. This is distinctly visible on the right side of the skull; it projects backwards about an inch beyond the general occipital margin. Internal to this is an ossification, most of which is covered by the usual sculpture, though a small tract along the posterior border is nearly smooth. This is, in all probability, the epiotic. Owing to the longitudinal fracture above mentioned, the supraoccipital cannot be defined. In the lower jaw an angular, an articular, and a dentary piece seem to be distinguishable. The articular end is obscure. Displacement upwards has removed or concealed the internal parapet of the alveolar grove, which is not apparent in either ramus. Adjacent to the operculum of the right side is a large crushed bony plate, which exhibits its smooth internal surface. This is detached from its natural position; and its form cannot be accurately defined. It may belong to the pectoral limb. Behind this a small prismatic bone, probably a carpal bone, and a fragment of an elongated enamelled bone, probably a fin-ray, can be distinguished. Behind the cranium is a confused mass of scales; on a few of these a pattern, not unlike that of *Rhizodus*, is obscurely seen.

The features above described show plainly that *Rhizodus* is a Ganoid fish, and suggest that its place in the Order is not far from *Megalichthys*. The present specimen does not, it is true, present the most distinctive characters which the hard parts of a Ganoid may yield in a fossil state. The jugular plates are wanting; and there is no trace of fins or tail. Messrs. Hancock and Atthey have, however, described the jugular plates of the genus on what seems satisfactory evidence. According to their account, there are a median and two lateral plates covered with "strong vermicular sculpture, composed of hollows and ridges"*. There is therefore adequate ground for admitting *Rhizodus* to the Crossopterygian suborder. Its teeth are generally similar to those of *Megalichthys*, and are of two sizes—the larger being coarsely folded at the base, and dendrodont. It will be interesting to ascertain, whenever an opportunity shall offer, whether *Rhizodus*, like *Megalichthys*, has aggregated vomerine teeth.

A pectoral arch, attributed to this genus, is, or has been, preserved in the Edinburgh Museum. It is briefly noticed by Dr. John Young in the paper cited below. A more important specimen from the Gilmerton ironstone has lately been described by Dr. Traquair. This reveals "a great part of a well-marked clavicle, resembling in shape that of *Holoptychius*, and ornamented externally by reticulating ridges, furrows, and pits." There is also visible an interclavicle (?) and a pectoral fin. Systematists attach considerable importance to the condition of the paired fins in a fossil Crossopterygian fish. In this suborder two types of paired fin occur, the one ("acute-lobate") having an elongate and pointed patch of small scales along the middle of the fin, while in the other ("obtuse-lobate") the scales are limited to the base. This difference in external character is believed to correspond with a noteworthy difference in the solid framework of the limb. Recent fishes with acute-lobate fringed fins (*Ceratodus, Lepidosiren*) have them supported by an axial skeleton, whereas *Polypterus*, the sole living example of an obtuse-lobate Crossopterygian, has the fin-rays supported, as in Elasmobranchs and Teleostei, by ossicles arranged in transverse series. Dr. Traquair finds that in *Rhizodus* the pectoral fin is obtuse-lobate; and this important character serves to separate the genus from *Holoptychius*, with which it has almost uniformly been associated, while the affinity of *Rhizodus* to *Megalichthys* is strengthened thereby.

Leaving for the present all questions as to the value and compatibility of the suborders Dipnoi and Crossopterygii, the genera hitherto included under these names may be arranged in some such way as follows. While so much remains to be done in elucidating

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* Natural-History Transactions of Northumberland and Durham, vol. iii. pp. 83, 84 (1869).

the true relations of the genera, it is undesirable even to attempt to rectify the nomenclature of the groups.

A (acute-lobate).

Ceratodus.
Lepidosiren.
———
Dipterus.
Ctenodus.
———

Phaneropleuron.
———
Holoptychius.
Glyptolepis.

B (obtuse-lobate).

Megalichthys.
Osteolepis.
Diplopterus.
———
Rhizodus.
Rhizodopsis.
———
Glyptolæmus.

Glyptopomus.
Gyroptychius.
———
Polypterus.
———
Cœlacanthus.
Undina.
Macropoma.

It may be useful to future investigators if I enumerate the chief writings which deal with *Rhizodus*. They are as follows:—

Hibbert, "On the Limestone of Burdiehouse, Edinburgh," Trans. Roy. Soc. Edinburgh, vol. xiii. pt. i. pp. 202–214, t. viii. figs. 1, 2, t. ix. figs. 2, 3, 9, 10, t. x. figs. 1, 2, 3 (1835).

Owen, Odontography, p. 75, t. xxxv. fig. 2, tt. xxxvi., xxxvii. (1840–45).

Sedgwick and M'Coy, British Palæozoic Fossils, p. 611, 612, t. 30. fig. 17 (1855).

Huxley, "Essay on the Systematic Arrangement of the Fishes of the Devonian Epoch," Mem. Geol. Survey, Decade x. (1861).

Young, "Note on the Scales of *Rhizodus*," Quart. Journ. Geol. Soc. vol. xxii. p. 317 (1866).

Young, "Notices of new Genera of Carboniferous Glyptodipterines," *ib.* p. 596 (1866).

Hancock and Atthey, "Remains of Reptiles and Fishes from the Northumberland Coal-field," Nat. Hist. Trans. Northumberland and Durham, vol. iii. p. 81 (1869).

Traquair, "On some Fossil Fishes from the neighbourhood of Edinburgh," Ann. Nat. Hist. ser. 4, vol. xv. p. 258 (1875).

The thanks of those who may be interested in this subject are due to Prof. T. McKenny Hughes, M.A., the Woodwardian Professor of Geology, Cambridge, by whose permission the skull of *Rhizodus* is now described—and to Mr. Thomas Atthey, of Gosforth, Newcastle, who cleared the specimen from the matrix, and developed its features with much care and skill.

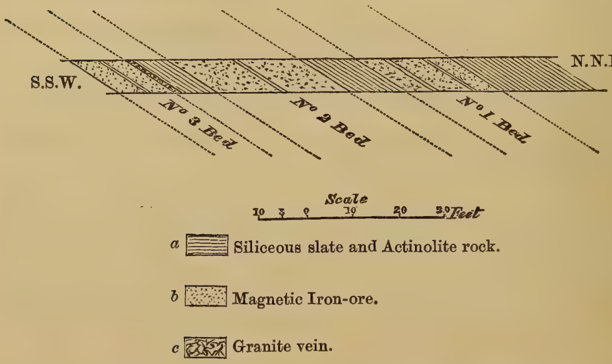
46. Notes *on* Haytor Iron-mine. By Clement Le Neve Foster, B.A., D.Sc., F.G.S. (Read June 23, 1875.)

It is nearly fifty years since this mine first attracted the attention of mineralogists by the occurrence of haytorite (chalcedony pseudomorphous after datholite). Several papers on the mineral were contributed to the Philosophical Magazine*; and an account of the mine was given by Mr. J. T. Kingston†. His description deals with the beds seen in an open work, and is so full and clear that there would be little left to add were it not for the fact that a new adit-level has intersected the beds and exposed a new section. There are certain points in this section which I think are worthy of being recorded; besides which it is well to call attention to the fact that there is now a good opportunity of studying the mode of occurrence of a fine deposit of magnetite without the necessity of making a journey to Norway or Sweden.

Haytor Mine is situated on the eastern borders of Dartmoor, about three quarters of a mile from the pile of granite rocks from which it derives its name. The iron-ore occurs in the form of thick beds of magnetite interstratified with altered shales and sandstones of Carboniferous age. Near the iron-ore the rock becomes highly charged with hornblende, and is sometimes apparently entirely made up of actinolite. Garnets, too, occur in great abundance in some places; and I also found a thin layer containing iron pyrites and what appears to be axinite.

The section seen near the end of the adit-level is shown in fig. 1.

Fig. 1.—*Section in the Adit-level in Haytor Mine.*



The exact thicknesses of the various beds were not measured by me, but were taken by the agent of the mine, Captain William Grose.

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* The Philosophical Magazine, vol. i. 1827, pp. 38, 40, 43; vol. x. 1831, p. 111. The Edinburgh Journal of Science, vol. vi. pp. 297 & 301.

† The Philosophical Magazine, vol. iii. 1828, p. 359.

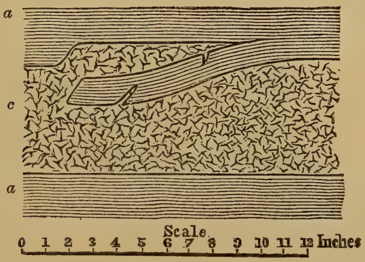
It appears that there are three beds of iron-ore. No. 1, or the uppermost, is 10 feet thick, with partings of rock giving about 2 feet of waste; No. 2 is 14 feet thick, with about 1 foot of waste; and No. 3 is proved to be at least 6 feet thick, with a similar amount of waste. There is altogether therefore a total thickness of some 26 feet of iron-ore. This is much more than is shown by Mr. Kingston; but then it must be recollected that the adit intersects the iron at a depth of some 20 fathoms below the old open work, and there has been plenty of room for changes in thickness of ore and partings to occur.

The beds strike about E. 25° S., and dip northwards 30°.

A fourth bed of magnetite, about 3 feet thick, is seen cropping out about 300 yards N.E. from the others, and appears to be running parallel to them.

It will be seen by referring to the Geological-Survey Map, Sheet 25 (where the outcrop of the iron is incorrectly marked), that the line of junction of the Granite and Carboniferous rocks is running here about north and south. Consequently, as the Carboniferous rocks strike about W. 25° N. against the granite, it is evident that the granite has broken across the strata here. This same fact is proved in another way. Just above No. 3 bed is a layer of fine-grained granite, 6 or 8 inches thick, running parallel to the stratification. At first sight it might be thought to be interbedded; but closer examination shows that it sometimes breaks across the stratification, as is seen in fig. 2. It is consequently an intrusive sheet, and, if it could be traced, would doubtless be found to be connected with the neighbouring mass of granite.

Fig. 2.—*Granite breaking across stratified rock, Haytor Mine.*



For explanation of letters see fig. 1.

Excepting this granite vein, the ore and enclosing rocks (*country*) have simply the appearance of altered strata. Beds of iron-ore deposited contemporaneously with shales and sandstones seem to have been subjected to a metamorphic action, probably due to the proximity of the granite. The iron-ore, perhaps originally in the form of beds like the Cleveland ore, has been altered into magnetite; whilst the change undergone by the shales and sandstones consists in an extreme silicification. It is, however, possible that the apparently stratified magnetite may have been formed by ferruginous emanations, which accompanied or followed the granitic intrusion, and spread out between the planes of bedding of the Carboniferous strata. The presence of actinolite and garnets, which I believe almost invariably accompany deposits of magnetite, may be explained under either hypothesis; these minerals were probably formed by metamorphic action out of the surrounding rocks, the ore furnishing the iron which enters into their composition.

The outcrop of these beds of magnetite may be traced eastwards for a distance of about three quarters of a mile. Near the surface the magnetite has been converted into ochre from the action of atmospheric agencies; and the outcrop has been worked for that substance.

In addition to the actinolite, garnets, axinite (?), and a little iron-pyrites, I also found chalcedony and crystallized chalybite occurring with the magnetite. A little fluor-spar seen on one of the rubbish heaps was probably derived from a small vein. I was not fortunate enough to obtain any haytorite.

47. *Descriptions of the* GRAPTOLITES *of the* ARENIG *and* LLANDEILO ROCKS *of* ST. DAVID'S. By JOHN HOPKINSON, Esq., F.L.S., F.G.S., and CHARLES LAPWORTH, Esq., F.G.S. (Read December 16, 1874.)

[PLATES XXXIII.-XXXVII.]

INTRODUCTION.

IN the neighbourhood of St. David's, the Arenig rocks, described by Mr. Hicks in his paper read at the last meeting of the Geological Society*, are the earliest in which Graptolites are known to occur; and yet, when once they appear, so diversified are their forms that these Pembrokeshire rocks are only equalled, in the number and variety of the genera they contain, by the Canadian Graptolite-bearing rocks of equivalent age known as the Quebec Group. In more ancient deposits two species only, belonging to one of the two great sections into which these fossils are divided, have hitherto been detected, viz. *Dictyograptus* (*Dictyonema*) *socialis*, Salter, and *Dendrograptus Hallianus*, Prout. The former occurring in the lower portion of the Tremadoc rocks of North Wales, and the latter in the equivalent strata (the Potsdam Sandstone of America), it is impossible to say which genus is the earlier, or whether the group is first represented in Britain or in America.

Before the discovery, in 1872, of the extensive series of Graptolites which characterize the Lower Arenig rocks of Ramsey Island, the Skiddaw Slates of Cumberland were supposed to be our earliest Graptolite-bearing rocks; but it is now known that the lowest rocks of the Arenig Group exposed in the vicinity of St. David's, in which Graptolites abound, are of greater age than any part of the Skiddaw Slates yet described; and it is highly probable that they are also older even than the lowest beds of the Quebec Group known to contain Graptolites, as will presently be shown.

As early as 1841 Graptolites were discovered in the "black slaty rocks of Pembrokeshire" (in the Llandeilo series) by Sir Henry De La Beche; and soon afterwards Professor Ramsay found the well-known species *Didymograptus Murchisoni* in the Llandeilo rocks of Abereiddy Bay; but it is not until 1866 that we find the first mention of the occurrence of these fossils in the older rocks of this district. In their 'Second Report' on the St. David's rocks, presented to the British Association in that year (1866), Messrs. Salter and Hicks mention the occurrence of the genera *Didymograptus* and *Dendrograptus* in the black slates and flags of Whitesand Bay, which they then recognized as being of Arenig age; and in the same year, in a paper by Mr. Wyatt Edgell, "On the Arenig and Llandeilo Groups"†, the

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* "On the Succession of the Ancient Rocks in the vicinity of St. David's, Pembrokeshire, with special reference to those of the Arenig and Llandeilo Groups, and their Fossil Contents." Quart. Journ. Geol. Soc. vol. xxxi. p. 167.

† Proc. Geologists' Assoc. July 1866. Geological Magazine, vol. iv. p. 113.

genus *Dictyonema* (*Dictyograptus*) is also mentioned as occurring at Whitesand Bay, where it had been discovered by Mr. Hicks in the lowest beds of the series.

In 1872 the discovery in the Arenig rocks of Ramsey Island and Whitesand Bay of about twenty species of Graptolites, identical with, or nearly allied to, those of the Quebec Group of Canada, and related, but not so nearly, to those of the Skiddaw series, proved that we had in these rocks a nearer representative of the Quebec Group than was before known to be present in Britain*; and in the following year, the discovery of a higher series of Graptolitiferous rocks in Ramsey Island, with species all of which seemed to be identical with those of the Skiddaw Slates, showed that the Skiddaw series was of more recent age than the lowest portion of the Arenig rocks of St. David's†.

This summer (1874) several new species of Graptolites have been found by Messrs. Hicks and Hopkinson in the Arenig rocks of Whitesand Bay; and a few species have also been found in beds underlying the Lower Llandeilo rocks of Abereiddy Bay at a quarry near Llanvirn. This assemblage of species is just such as occurs in the highest beds of the Skiddaw Slates and Quebec Group, proving that we have here, as in the higher Graptolitiferous rocks of Ramsey Island, beds of Upper Arenig age.

In the Lower Llandeilo series of Abereiddy Bay, again, several species of Graptolites have been found, most of them being new; and a few species have also been collected in the higher Llandeilo rocks exposed in Abereiddy Bay; but here there is much more work to be done before we can form any idea of the number of species they may contain, and of the number of distinct zones into which their species will enable us to divide them.

CLASSIFICATION.

The Graptolites to be described in the present paper include the whole of the species collected within the last three years on the occasions referred to, of which specimens sufficiently perfect for determination or description have been obtained.

The classification and nomenclature of the containing rock-groups and their subdivisions is that adopted by Mr. Hicks in his Memoir already cited on the Arenig and Llandeilo rocks of Pembrokeshire. The arrangement of the fossils themselves will be found to differ in several material respects from that generally current amongst palæontologists. The order in which they will be described is indicated in the following synoptical table, in which the genera already known as occurring in the Arenig and Llandeilo rocks of the neighbourhood of St. David's are printed in italics.

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* Brit. Assoc. Report for 1872, Sections, p. 107. Proc. Liverpool Geol. Soc. 1872–73, p. 36.

† Brit. Assoc. Rep. 1873, Sections, p. 82. Proc. Liverpool G. S. 1873–74, p. 47.

Class **HYDROZOA,** *Huxley.*

Order HYDROIDA, *Huxley.*

Division **Graptolithina,** *Bronn.*

Sub-orders.	Sections.	Families.	Genera.
RHABDOPHORA (*Allman*).	GRAPTOLOIDEA.	Monograptidæ	Rastrograptus*, *Barr.*
			Monograptus, *Gein.*
			Cyrtograptus, *Carr.*
		Nemagraptidæ	Pleurograptus, *Nich.*
			Amphigraptus, *Lapw.*
			Leptograptus, *Lapw.*
			Cœnograptus, *Hall.*
			Nemagraptus, Emmons.
		Dichograptidæ	*Didymograptus*, M'Coy.
			Tetragraptus, Salter.
			Dichograptus, *Salter.*
			Loganograptus, *Hall.*
			Clonograptus, *Hall.*
			Clematograptus, Hopk.
		Dicranograptidæ	*Dicellograptus*, Hopk.
			Dicranograptus, *Hall.*
		Diplograptidæ	*Climacograptus*, Hall.
			Diplograptus, M'Coy.
			Subgen. *Glyptograptus*, Lapw.
			Subgen. Petalograptus, *Süss.*
			Subgen. Cephalograptus, *Hopk.*
			Subgen. Orthograptus, *Lapw.*
		Phyllograptidæ	*Phyllograptus*, Hall.
	RETIOLOIDEA	Glossograptidæ	*Glossograptus*, Emmons.
			Retiograptus, *Hall.*
			Lasiograptus, *Lapw.*
		Gladiograptidæ	Clathrograptus, *Lapw.*
			Trigonograptus, Nich.
			Gladiograptus*, *Barr.*
	CORYNOIDEA	Corynograptidæ	Corynograptus*, *Nich.*
CLADOPHORA (*Hopkinson*).	THAMNOIDEA	Thamnograptidæ	Thamnograptus, *Hall.*
			Buthograptus, *Hall.*
	DENDROIDEA	Ptilograptidæ	*Ptilograptus*, Hall.
		Callograptidæ	*Dendrograptus*, Hall.
			Callograptus, Hall.
			Dictyograptus, Hall.
			Subgen. *Desmograptus*, Hopk.

The arrangement of the Rhabdophora adopted is that originally proposed in Mr. Lapworth's paper on an Improved Classification of the Rhabdophora, published in the 'Geological Magazine' for November and December, 1873. The genera included under this head present among themselves extraordinary morphological diversities. The most extreme types, however, appear to be connected by known intermediate forms; and they constitute collectively a well-marked, compact, natural group.

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* The slight alterations in the terminations of these names have been made with the concurrence of the founders of the respective genera.

The so-called "dendroid" Graptolites are here for the first time united by Mr. Hopkinson into a suborder under the title of Cladophora. That the classification of the genera included in this suborder is to a certain extent artificial is admitted; but the facts at our disposal, while they afford conclusive evidence of the deficiencies of the scheme here proposed, are as yet insufficient to enable us to make any more satisfactory arrangement. It may be objected that the name given to the suborder is not sufficiently distinctive, many of the Rhabdophora being branching forms; but the tree-like mode of growth of these genera, all of which *bear branches*, in which respect they differ collectively from the Rhabdophora, seems sufficient to warrant their being connected together under the term Cladophora. The two sections into which they are grouped (*shrub-like* and *tree-like*) also point out this as an appropriate term. They all seem to have been fixed forms, differing in this respect, as in their mode of growth, from the Rhabdophora, to which they are possibly allied through the genus *Thamnograptus*, which, with the somewhat anomalous genus *Buthograptus*, forms the section Thamnoidea.

The section Dendroidea here includes the genera originally grouped together under this head by its founder, Professor Nicholson, in the first part of his 'Monograph of the British Graptolitidæ.' These genera fall naturally into two families, the first of which, *Ptilograptidæ*, connects the section with the Thamnoidea, and apparently forms a connecting link between the Cladophora and their recent allies the Thecaphora, *Ptilograptus* seeming to be a true Sertularian zoophyte. The three genera of the Callograptidæ are almost inseparably connected through some of their species, the intermediate forms being comprised in the genus *Callograptus*.

DISTRIBUTION AND CORRELATION.

The present state of our knowledge of the distribution of the Graptolites in the vicinity of St. David's is shown in the accompanying Table, in which every species noticed is referred to its exact position in the vertical series.

Graptolites are first known to occur in the lowest beds of the Arenig rocks exposed in Whitesand Bay. It is an interesting fact that the Cladophora only have as yet been found here, and that the two genera of the Tremadoc rocks, *Dendrograptus* and *Dictyograptus*, are here represented, associated for the first time with the zoologically intermediate form *Callograptus*, species of which, too badly preserved for determination, occur a few feet lower than the small group of Dendroidea here referred to. Of *Dictyograptus* a single species only has here been found; and although several species of *Callograptus* and *Dendrograptus* are known to occur, there are only two species of each genus of which specimens sufficiently perfect for description have been collected. All these species are new, and therefore useless for purposes of comparison.

Very near to this horizon, but most probably rather higher, are the beds exposed on the north-eastern coast of Ramsey Island, at

Table showing the Distribution of the Graptolites in the Arenig and Llandeilo Rocks of St. David's.

	Arenig.						Llandeilo.			
	Lower.		Middle.		Upper.		Lower.		Mid.	Up.
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Rhabdophora.	Whitesand Bay.	Ramsey Island.	Whitesand Bay.	Whitesand Bay.	Llanvirn.	Ramsey Island.	Ab	erei	ddy	Bay.
Didymograptus affinis, *Nich.*	...	...	...	...	...	*				
—— bifidus, *Hall*	...	...	...	...	*	*				
—— euodus, *Lapw.*	...	...	...	...	...	...	*			
—— extensus, *Hall*	...	*								
—— furcillatus, *Lapw.*	...	...	...	...	...	*				
—— indentatus, *Hall*	...	...	...	...	...	*				
—— ——, var. nanus, *Lapw.*	...	...	...	...	*	...	*	*		
—— Murchisoni, *Beck*	...	...	...	...	...	...	*	*		
—— Nicholsoni, *Lapw.*	...	...	...	...	*	...				
—— patulus, *Hall*	...	...	*	...	*					
—— pennatulus, *Hall*	...	*								
—— sparsus, *Hopk.*	...	*								
Tetragraptus quadribrachiatus, *Hall.*	...	...	*							
—— Halli, *Hopk.*	...	...	*							
—— Hicksii, *Hopk.*	...	...	*							
—— serra, *Brong.*	...	...	*							
Clematograptus implicatus, *Hopk.*	...	...	*							
Nemagraptus capillaris, *Emm.*	...	...	...	...	*					
Dicellograptus moffatensis, *Carr.*	...	...	...	...	*	...	...	...	*	
Climacograptus cælatus, *Lapw.*	...	...	...	...	...	...	*			
—— confertus, *Lapw.*	...	...	...	...	...	*				
Diplograptus dentatus, *Brong.*	...	...	...	...	*	*				
—— foliaceus, *Murch.*	...	...	...	...	...	...	*	*	*	
—— tricornis, *Carr.*	...	...	...	...	...	...	*	*	*	
Phyllograptus stella, *Hopk.*	...	*								
Glossograptus ciliatus, *Emm.*	...	...	...	...	*					
Trigonograptus ensiformis, *Hall*	...	*								
—— truncatus, *Lapw.*	...	*								
Cladophora.										
Ptilograptus acutus, *Hopk.*	...	...	...	...	...	...	*			
—— cristula, *Hopk.*	...	*								
—— Hicksii, *Hopk.*	...	*								
Dendrograptus arbuscula, *Hopk.*	*	*	*							
—— diffusus, *Hall*	...	*								
—— divergens, *Hall*	...	*								
—— flexuosus, *Hall*	...	*	*							
—— ——, var. recurvus, *Hopk.*	...	*								
—— persculptus, *Hopk.*	*									
—— Ramsayi, *Hopk.*	...	...	...	...	...	...	...	*		
—— serpens, *Hopk.*	...	...	...	...	...	...	*			
Callograptus elegans, *Hall*	...	...	*							
—— radiatus, *Hopk.*	*	*								
—— radicans, *Hopk.*	*	*								
—— Salteri, *Hall*	...	...	*							
Dictyograptus cancellatus, *Hopk.*	*									
—— Homfrayi, *Hopk.*	...	*								
—— irregularis, *Hall*	...	...	*							
—— sp. ind.	...	...	...	...	...	...	...	*		

Road Uchaf, where such an extensive and varied series of Graptolites was discovered in 1872. Here the section Dendroidea is completed by the addition, to the three genera already enumerated, of the somewhat remotely allied genus *Ptilograptus*; and at least three of the species from Whitesand Bay occur.

Of the nine species of Cladophora from this locality, three, viz. *Dendrograptus diffusus*, *D. divergens*, and *D. flexuosus*, occur in the Quebec Group of Canada, while the rest are new. The Rhabdophora appear to come in here for the first time, and are represented by three genera with six species, of which three, viz. *Didymograptus extensus*, *D. pennatulus*, and *Trigonograptus ensiformis* occur also in the Quebec Group, the others being new.

From the occurrence amongst these fifteen species of three that are found in the previously mentioned Whitesand-Bay beds, and of six Quebec species, taken in connexion with the absence (so far as known) of any Quebec species in the lower Whitesand-Bay beds, and of their greater prevalence in the higher Arenig rocks of Whitesand Bay and elsewhere, it would appear that we have here as early a series of rocks as any known to be present in the Graptolite-bearing portion of the Quebec Group, and perhaps a rather earlier series. It may also be remarked that we have not yet a single Skiddaw-Slate species.

A somewhat similar fauna, with at least two identical species, *Dendrograptus diffusus* and *D. flexuosus*, has been discovered within the last few years in the Arenig rocks at Shelve Church in Shropshire. The species which occur here seem, however, more nearly allied to those of the series next to be noticed, the Middle Arenig rocks of Whitesand Bay. It is in these rocks that we have the first indication of an approach to the fauna of the Skiddaw series—the funiculate Dichograptidæ, so fully represented in the lower beds of this series, appearing for the first time in the St.-David's area in the Middle Arenig rocks. Of the Rhabdophora, *Didymograptus patulus*, *Tetragraptus serra*, and *T. quadribrachiatus* are common to the two localities; but the Cladophora, which are well represented here, are very sparingly distributed in the Skiddaw area.

This Middle Arenig subformation is even more nearly allied by its Graptolites to the Point-Lévis shales of the Quebec Group of Canada, in which nearly all its species, both of Rhabdophora and Cladophora, have been found.

In the Graptolite zone of Shelve Church, already mentioned, many of the species which occur low in the Middle Arenig series of St. David's have lately been recognized. *Didymograptus patulus*, *Clematograptus implicatus*, *Dendrograptus diffusus*, *D. flexuosus*, *Callograptus elegans*, and *C. Salteri* are known in both localities*.

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* *Didymograptus patulus* and a *Dictyonema* were detected at this locality by Mr. Morton of Liverpool some years ago (*vide* his "Geology of the Country around Shelve," Proc. Liverpool Geol. Soc., Session 1868–69). The remaining species noticed above, together with several additional forms, previously only known to occur in the Skiddaw and Point-Lévis beds, were discovered by Mr. Hopkinson in 1872 and the present year (1874).

The only other district in Britain in which similar Graptolites are known to occur is near the Arenig Hills in Merionethshire, from which this formation takes its name; and although Graptolites and other fossils had been collected in the Arenig area to the north-west of these hills many years ago by Professor Sedgwick and Mr. Salter, it is only in the present year that the equivalency of the containing beds with the strata we are now considering has been conclusively proved.

Species of Rhabdophora characteristic of the Middle Arenig rocks of St. David's also occur in the alum-slates of Sweden, in the lower zones of the Oslo Group of Norway, in Russia, and in Newfoundland; and the valuable paper of Mr. R. Etheridge, jun., on the Graptolites of Victoria*, enables us to recognize them as present even in the antipodal Graptolitic rocks of the continent of Australia.

Of the well-marked group of Rhabdophora furnished by the Upper Arenig rocks of Llanvirn and Ramsey Island, most of the species, including *Didymograptus patulus*, *D. bifidus*, *D. indentus*, *D. Nicholsoni*, *Climacograptus confertus*, and forms intimately allied to *Glossograptus ciliatus* and *Nemagraptus capillaris* are found in the Upper Skiddaw Slate series of Professor Nicholson, the same species occurring in Wales and in Cumberland in almost exactly the same relative abundance. Similar Graptolites are yielded by the shales lying immediately below, and by those interstratified with, the earliest trappean beds surmounting the great mass of the so-called Lower Llandeilo rocks (Arenigs) of the neighbourhood of Shelve, Shropshire. *Didymograptus patulus*, *D. bifidus*, *D. Nicholsoni*, and *Diplograptus dentatus* are here also the predominating forms.

It is a noteworthy circumstance that three of the most peculiar fossils of this Upper Arenig subformation, viz. *Nemagraptus capillaris*, *Glossograptus ciliatus*, and *Diplograptus dentatus*, are found in the Taconic Shales of Dr. Emmons, a subdivision of that enigmatical series of rocks which runs through the eastern portion of the State of New York parallel with the course of the Hudson River.

The Graptolites afforded by the well-known black shales of the true Lower Llandeilo subformation as exposed in Abereiddy Bay, form collectively a much larger group than those yet furnished by equivalent deposits elsewhere in Britain. The four species of Cladophora are as yet wholly restricted to this locality; but many of the Rhabdophora have a wide geographical range.

The most characteristic Graptolite of the Lower Llandeilo beds (*Didymograptus Murchisoni*) occurs in abundance in dark shales associated with and surmounting the higher portion of the trappean group of Shelve—beds which admit of almost exact parallelism with the Lower Llandeilos of Abereiddy Bay on many other grounds. The same species is also found in the strata which imbed the felspathic traps and ashes of the neighbourhood of Builth and Llandrindod. Here also it is associated with *Diplograptus foliaceus*, *D. tricornis*, and *Climacograptus cælatus*, its constant companions in the lowest zone at Abereiddy.

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* Ann. & Mag. Nat. Hist., July 1874.

Two varieties of *Didymograptus Murchisoni*, viz. *Didymograptus virgulatus*, Beck, and *D. geminus*, Hisinger, are abundant in the possibly synchronous deposits of black Graptolitic shales containing the Orthoceratite Limestone of Southern Norway.

Several of the Rhabdophora met with in the Middle Llandeilo beds of Abereiddy Bay are furnished by the corresponding calcareous schists of Builth, *Diplograptus foliaceus*, *D. tricornis*, and *Dicellograptus moffatensis* being common to the two localities. A more intimate connexion, however, is shown by the Lower Moffat beds of South Scotland, in which all the forms as yet obtained from the Middle Llandeilo beds of Abereiddy Bay are abundant and characteristic.

The Graptolites now known to occur in the Arenig and Llandeilo Rocks of St. David's make up a total number of 45 species, belonging to 14 distinct genera.

Of these genera the suborder Cladophora claims four, viz. *Ptilograptus*, *Dendrograptus*, *Callograptus*, and *Dictyograptus*, all of which appertain to the section Dendroidea. Some genera of this section have been recognized in the Tremadoc rocks of North Wales and in the equivalent deposit of the Potsdam Sandstone in Iowa. The whole of them retain their distinctive characters, without material alteration, from the Arenig rocks of Pembrokeshire to the Ludlow rocks of Shropshire; one at least occurs in beds of Devonian age in North America; and, as far as outward characters enable us to judge, they appear to have their representatives in the seas of the present day.

Although the Dendroidea in these beds are surprisingly numerous, the genera constituting the section of the Thamnoidea are apparently wanting. Examples swarm abundantly in South Scotland, and are known also in the older shales of Point Lévis: the St.-David's beds however have not afforded us a single fragment.

The suborder Rhabdophora, which includes all the more typical Graptolites, makes its first appearance (as far as at present known) in the Lower Arenigs of Ramsey Island, and finally dies out in the Ludlow rocks of Shropshire.

Of the genera belonging to this suborder found at St. David's, two only, *Trigonograptus* and *Glossograptus*, appertain to the section Retioloidea. Not a single specimen has been collected that can with certainty be referred to the section Corynoidea—another striking example of the apparently capricious distribution of some families, a circumstance due in all probability to our present imperfect acquaintance with these strata.

The great section of the Graptoloidea claims the whole of the remaining eight genera. Exactly as in America, Cumberland, and Norway, the family of the Dichograptidæ is most fully represented. This family, which is strictly confined to the Arenig and Llandeilo formations, is represented in the St.-David's rocks by three genera—its species, with their characteristic long feathery branches, being first known in Britain in the Lower Arenigs of Ramsey Island, and passing insensibly away at the summit of the Llandeilo. The peculiar funiculate genera are found in abundance in the Middle Arenigs of Whitesand Bay, approximately on the same horizon on which they occur at Skiddaw and Point Lévis.

A single genus belonging to each family proves the presence of the Nemagraptidæ, the Dicranograptidæ, and the Phyllograptidæ. Both genera of the family Diplograptidæ are pretty fully represented, both coming in together in the Middle Arenig, as in Norway, Cumberland, and Canada.

In spite of the great additions to our knowledge of the Graptolite fauna of these beds made by these researches, a comparison of the species given in the Table with those yielded by the corresponding deposits of Skiddaw, Canada, Norway, and South Scotland, while it shows many new forms, shows also a remarkable absence of some of the most characteristic forms common to these widely separated areas. As many of them occur, however, at Shelve and elsewhere, it is more than probable that they will ultimately be detected in the St.-David's area.

The many remaining points of resemblance and contrast that may be instituted between the fauna of these beds of St. David's and their equivalents elsewhere, cannot here be even alluded to. The most superficial comparison of the list of species given in the Table, with those of the localities already so frequently adverted to, will at once convince the palæontologist that the general facies of the Graptolitic fauna of any subformation of the area under consideration is almost identical with that of the synchronous rock-groups elsewhere. Perhaps the most patent result of these researches is the circumstance that they clearly demonstrate that the Hydroida of these ancient rocks, so long shunned or misinterpreted by the systematist, are rapidly emerging from the obscurity which has enveloped them, and will perhaps soon stand side by side with the better-understood Brachiopoda and Crustacea, as unerring exponents of the true geological age of the most widely separated rocks in which they are found.

TERMINOLOGY, &c.

The discovery of the nature and function of the *sicula*, and of its relations to the adult Graptoloid, has thrown great light upon several disputed points in the morphology of the Rhabdophora; and several structural features, formerly believed to be of no special importance, have been brought into great prominence by recent researches amongst the Graptolites in general. This necessitates the employment of a few new terms, and more precise definitions of some others that have already obtained general acceptance. Only those, however, will here be noticed which are immediately connected with the forms described in the present communication.

1. *Sicula.*—The chitinous covering of the free zooid, "germ," or embryo, in the Graptoloidea. Its original form was probably that of a minute hollow cone; but, in its present state, flattened upon the stone, it usually presents the appearance of an elongate, triangular film of chitine, in which a slender longitudinal thread is immersed, one end of which is slightly projecting.

The two main branches of each bilateral Graptoloid originate from approximately opposite points, at, or near, the broad end of the *sicula*, and either grow backward along its length, almost completely imbedding it, and coalesce by their dorsal walls into a diprionidian or tetraprionidian structure, or, proceeding freely outwards at various angles, give rise to a symmetrical, simple or compound monoprionidian polypary. The sicula meanwhile, when not imbedded, either gives origin to a central branch, is absorbed, or, increasing somewhat in size, retains permanently the precise form and proportions it possessed at the period when the main branches were given off. This persistent sicula forms a very conspicuous feature in several monoprionidian genera, and constitutes the " axillary spine " of some authors, and the "radicle " (in part) of others.

In all the *siculate* Graptolites the mode of origin of the branches is almost identical. The notable differences observable in the ultimate form assumed by the polypary in the various genera, are all primarily due merely to the direction assumed by the main branches as they grow onward from their point of origin in the sicula. This direction remains much the same when our observations are restricted to a single genus; but within the limits of the section of the Graptoloidea every gradation is recognizable, from forms in which the dorsal walls of the two primary branches are wholly coalescent, to forms in which the ventral margins are almost in contact. The actual relations of the sicula and branches, however, remain invariably the same throughout. The major extremity of the sicula being always situated on the same side of the axil as the ventral margins of the branches, its minor extremity consequently invariably bisects the angle formed by their dorsal margins. The fact that the major extremity of the sicula forms the proximal end of the complete polypary in *Diplograptus* and *Dicranograptus* decides conclusively the controverted question as to whether the dorsal or the ventral margin in *Dicellograptus* and *Didymograptus* ought properly to be regarded as proximal. In future, therefore, the whole of the Graptoloidea, without exception, must be figured with the major extremity of the sicula placed below—or, in other words, with the pointed end of the sicula directed upwards.

This conclusion also determines that the dorsal angle is invariably the theoretical "*angle of divergence*;" for in *Diplograptus* and *Climacograptus* it is unquestionably 0°, the polypary in these genera being composed, actually or theoretically, of two branches which do not diverge at all from each other, but are conjoined for the whole of their length. In *Dicranograptus* the branches are conjoined for some distance and then diverge at an angle of less than 180°. In the closely allied genus *Dicellograptus* the branches are non-coalescent, and diverge at an angle of less than 180° immediately from their point of origin. Through the genus *Leptograptus* and its allies, in which the angle of divergence always approximates to 180°, we pass from *Dicellograptus* to the homomorphous but very distinct genus *Didymograptus*, in which the angle of divergence is gradually carried through the various species from 180° almost to 360°, the branches being finally brought round so that, instead of their dorsal margins coalescing as in *Diplograptus*, their ventral margins actually face each other in parallel lines.

2. *Appendages of the polypary.*—The so-called "ornaments" or extraneous appendages of the polypary in the Rhabdophora consist originally of marginal spurs or processes, simple or branching, free or anastomosing. They are either lateral, ventral, or terminal in position.

The *lateral* or *peridermal* appendages are strong spurs (*Glossograptus*), or long branching processes (*Neurograptus* &c.), originating directly from the virgula, and forming when complete a longitudinal series extending down the median (*septal*) line of the periderm at right angles with the hydrothecæ.

The *ventral* or *thecal* appendages are either proximal, mesial, or apertural in position.

The *proximal* and *mesial* appendages are invariably azygous, simple spurs, or spines, given off from a fixed point in the middle line of the outer margin of the theca—the former at its proximal end (*Climacograptus*), the latter midway along its length (*Dicellograptus*).

The *apertural* spines proceed from the outer margin of the orifice of the hydrotheca, and either occur singly (*Glyptograptus*) or in pairs (*Orthograptus*). Normally simple and free, they sometimes support between them a flat chitinous plate or "vesicle." In some genera (*Lasiograptus* &c.) they anastomose and form a continuous braiding of *marginal meshes*.

The *proximal* (or *radicular*) spurs, or first-formed thecal spines, whether mesial or apertural, attain in many species an extraordinary development; and, like their diminutive homologues, they sometimes support between them a "vesicle" or "disk;" but they are not yet known to branch or anastomose.

3. *Radicle.*—This term was first suggested to Professor Hall by his theory that some of the Rhabdophora were at least temporarily affixed to the sea-bottom or to foreign objects. In the forms which he believed to be permanently free, he clearly characterized it as being actually the proximal prolongation of the solid axis (*virgula*). In spite, however, of this rigid definition, the term has been applied indiscriminately, by its eminent founder and by those palæontologists who have since employed it, both to the proximal end of the virgula and also to the persistent sicula itself. A whole family (Dichograptidæ) of the Graptoloidea, and many genera belonging to other families, have consequently been always figured in an inverted position. Our improved acquaintance with the true relations of the sicula and branches will effectually prevent the repetition of this formerly natural, and perhaps inevitable error. The term *radicle* may therefore for the present be retained with advantage exactly in the letter of Hall's definition—*i. e.* as the distinctive title of the proximal prolongation of the virgula, whether that of the polypary itself (Diplograptidæ), or that of the persistent sicula (Nemagraptidæ, &c.).

DESCRIPTIONS OF THE SPECIES.

Suborder *RHABDOPHORA*, Allman.

Section GRAPTOLOIDEA, Lapworth.

Family DICHOGRAPTIDÆ, Lapworth.

Genus DIDYMOGRAPTUS, M'Coy.

DIDYMOGRAPTUS EXTENSUS, Hall, sp. Pl. XXXIII. figs. 1*a*–1*d*.

1858. *Graptolithus extensus*, Hall, Report of Geol. Surv. of Canada for 1857, p. 131.

1865. *Graptolithus extensus*, Hall, Grapt. Quebec Group, p. 80, pl. ii. figs. 11–16.

1870. *Didymograpsus extensus*, Nich. Ann. & Mag. Nat. Hist. ser. 4, vol. v. p. 341, pl. vii. figs. 2, 2*a*.

Branches long and slender, becoming gradually wider from their origin for the greater part of their length, diverging from each other at an angle of 180°; sicula minute; hydrothecæ about 24 to the inch, inclined to the axis at an angle of about 40°, two or three times as long as wide, very slightly curved, and with their outer margins free for one third to one half their length; apertures with a truncate margin; apertural angle* 90° to 120°.

Our specimens differ from Hall's description only in the angle made by the margin of the apertures, which varies considerably even in the same individual. But this is probably merely owing to varying direction of compression, and Hall's figures show that in this respect the British and Canadian forms do not materially differ. One result of perhaps compression and cleavage combined is shown in fig. 16, in which one branch, near its origin, is seen to have only 20, while in the other the proportion is nearly 40 thecæ to the inch. The actual number has here (near the origin of the branches) most probably been about 25 or 30 in an inch.

In an unusually well preserved specimen, consisting of one entire branch with a small portion of the other, the distal extremity is seen to gradually diminish in width to nearly the same extent as the proximal. The specimen is partly preserved in relief, a very rare occurrence in the St.-David's rocks. The presence of the virgula is distinctly indicated by a slight elevation at the dorsal margin of the branch; and the periderm, again, is well marked and considerably more prominent than the hydrothecæ. In a transverse section the hydrothecæ would appear to become narrower towards their apertures. Where the substance of the Graptolite is removed, the individual hydrothecæ are even more clearly defined than where they are shown in relief; and their proximal margin, or line of junction

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* The angle made by the aperture with the general axis of the branch.

with the supporting periderm, is indicated in one or two instances by a slight ridge.

The maximum width of the branches observed in any specimen is one fifteenth of an inch, and their greatest length 4 inches.

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

DIDYMOGRAPTUS SPARSUS, Hopk., sp. nov. Pl. XXXIII. figs. 2 *a*–2 *d*.

Brit. Assoc. Report, 1872.

Branches linear, elongate, nearly as wide at their origin as at any part of their length, diverging from each other at a primary angle of about 240°, which by their curving soon becomes 180°; sicula large, obtusely pointed; hydrothecæ 15 or 16 to the inch, inclined to the axis at an angle of about 45°, twice as long as wide, and free for half their length; apertural angle about 90°, margin truncate.

This species differs from nearly all the others of its genus, and from *all* to which it is nearly allied, in the distance its thecæ are apart; the width of the branches at their origin, which is one sixteenth of an inch, is another characteristic; whilst the unusually large sicula, from which the branches proceed with a graceful curve, forms such a conspicuous feature that it is usually alone sufficient to indicate the species.

The maximum width of the branches is one tenth of an inch; the geatest length observed, 3 inches.

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

DIDYMOGRAPTUS PENNATULUS, Hall, sp. Pl. XXXIII. figs. 3 *a*–3 *e*.

1865. *Graptolithus pennatulus*, Hall, Grapt. Quebec Group, p. 82, pl. iii. figs. 1–8, pl. v. fig. 9 (?).

Branches narrow at their origin, more or less rapidly increasing in width for about two thirds of their length, and then contracting towards their extremities, diverging from each other at an angle of about 180° or 200°; hydrothecæ from 25 to 30 to the inch, long, narrow, and slightly curved outwards, inclined to the axis at an average angle of from 40° to 60°, six (to eight) times as long as wide, and with their outer margins free for about a sixth of their length; apertural angle from 100° to 120°, margin concave; denticles slightly mucronate.

This species may be readily distinguished from all the others of its genus by the narrowness of the branches at their origin and the great width they ultimately attain. Measuring near their origin not more than three or four hundredths of an inch, they frequentlty attain a maximum width of three tenths of an inch. The resemblance between our specimens and Hall's figures is remarkably close. From the species which are associated with the fragment he refers with much hesitation to this species (Gr. Queb. Group, pl. v. f. 9), it seems more probable that it belongs to this than to *D. bifidus*, a species occurring in much higher beds.

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

DIDYMOGRAPTUS PATULUS, Hall, sp. Pl. XXXIII. figs. 4*a*–4*e*.

1858. *Graptolithus patulus,* Hall, Rep. Geol. Surv. Canada for 1857, p. 131.
1863. *Didymograpsus hirundo,* Salter, Quart. Journ. Geol. Soc. vol. xix. p. 137, fig. 13*f*.
1866. *Graptolithus patulus,* Hall, Grapt. Quebec Group, p. 71, pl. i. figs. 10–15.
1870. *Didymograpsus patulus,* Nich. Ann. & Mag. Nat. Hist. ser. 4, vol. v. p. 340, pl. vii. figs. 1, 1*a*.

Branches long, linear, widening very gradually from their origin to near their extremities, diverging from each other at an angle of 180°, or sometimes rather more; sicula minute; hydrothecæ 20 to 24 to the inch, inclined to the axis at an angle of from 45° to 60°, three to four times as long as wide, and with their outer margins free for about one fourth their length; apertural angle normally 130°, with a concave margin forming with the outer margin curving mucronate denticles.

The specimens of this species described by Prof. Nicholson from the Skiddaw Slates differ slightly from those from which the above description is drawn up. In these, as in the specimens from the Quebec Group, there are about 24 thecæ in the space of an inch (sometimes rather fewer), while in the Skiddaw-Slate specimens the number is from 32 to 34; but in the other characters they agree with our specimens.

As shown in figure 4*d*, the thecæ sometimes lose all the characters by which the species can be determined, varying so greatly in a single branch that, if one part of the branch were separated from the other, the two portions would be referred without a doubt to different species.

Loc. Middle Arenig, Whitesand Bay (*Salter*). Upper Arenig, Llanvirn Quarry, and Porth Hayog, Ramsey Island.

DIDYMOGRAPTUS NICHOLSONI, Lapw., sp. nov. Pl. XXXIII. figs. 5*a*–5*d*.

1868. *Didymograpsus serratulus,* Nicholson (*non* Hall), Quart. Journ. Geol. Soc. vol. xxiv. p. 136.
1870. *Didymograpsus serratulus,* Nich. Ann. & Mag. Nat. Hist. ser. 4, vol. v. p. 343, pl. vii. figs. 3, 3*a*, 3*b*, &c.

Branches long, usually straight, and somewhat rigid, diverging from a distinct sicula at an angle of about 240°, and having a fairly uniform width of about one twentieth of an inch throughout; hydrothecæ from 25 to 30 to the inch, inclined at an angle of about 30° to the axis of the branch, the concave apertural and outer margins generally compressed into a long acute denticle.

Numerous imperfect examples of this species were collected some years since by Professor Nicholson from the Skiddaw Slates of the Lake district, and by him provisionally referred to *D. serratulus*, Hall (Ann. & Mag. Nat. Hist. *loc. cit. supra*). Our better-preserved specimens, from Llanvirn, fully bear out his suspicions of its distinctness, and we have now sufficient evidence to describe it as new.

It differs from *D. serratulus* in the number and shape of its hydrothecæ. In that species there are but sixteen in the space of an inch, and the apertural margin of each is straight and almost at right angles with the line of the branch. In *D. Nicholsoni* the thecæ average twenty-six to the inch, and the deeply concave apertural margin is prolonged normally into a long oblique denticle.

It is named after its eminent discoverer and describer, Prof. H. A. Nicholson, of the Newcastle College of Science.

Loc. Upper Arenig, Llanvirn Quarry.

DIDYMOGRAPTUS AFFINIS, Nicholson. Pl. XXXIII. figs. 6*a*–6*c*.

1863. *Didymograpsus*, sp., Salter, Quart. Journ. Geol. Soc. vol. xix. p. 137, fig. 13*d*.

1869. *Didymograpsus affinis*, Nich. Ann. & Mag. Nat. Hist. ser. 4, vol. iv. p. 240, pl. xi. fig. 20.

1870. *Didymograpsus affinis*, Nich. ib. vol. v. p. 343, fig. 4.

Branches very slender, from half to three quarters of an inch in length, diverging from each other at an angle of from 210° to 270°; sicula slender, tapering to a point; hydrothecæ about 18 to the inch, inclined to the axis at an angle of from 15° to 20°, three or four times as long as wide, and with their outer margins free (apparently) for the whole of their length; apertural angle about 120°, margin slightly convex; denticles slightly mucronate.

Only one or two specimens showing the two branches have been seen, the species usually occurring as single branches looking exactly like fragments of *Monograptus Nilssoni*, Barr., as in the Skiddaw Slates, in which alone the species has before been found.

The only perceptible difference between our specimens and those from the Skiddaw series is in the form and angle of the apertures of the thecæ, which in the Skiddaw specimens are at right angles with the general axis of the branches, and have not the convex margin of the St.-David's forms. The convexity, however, is very slight, and is changed to a concavity, only just perceptible, at the distal submucronate extremity of the thecæ.

Loc. Upper Arenig, Porth Hayog, Ramsey Island.

DIDYMOGRAPTUS EUODUS, Lapw., sp. nov. Pl. XXXV. figs. 1*a*–1*c*.

Branches rigid, of great length, proceeding in opposite directions in the same straight line, except in the immediate neighbourhood of the axil, where they are slightly curved, diverging from a well-marked sicula with a primary angle of about 210°, and increasing in width from one fortieth to one twelfth of an inch in the first six inches of their length; hydrothecæ from 16 to 18 to the inch, inclined at an angle of from 30° to 40° to the axis of the branch; apertural margin concave, and forming, with the slightly curved outer margin, a prominent and almost equilateral denticle.

Of all our British species this form most nearly approaches the *D. serratulus* of Professor Hall (Pal. New York, vol. i. pl. 74. figs. 5*a*, 5*b*). It resembles his example in the remarkable rigidity of its branches, and presents us with exactly the same number of thecæ to the inch. It also occurs in association with *D. superstes*, Lapw. MS., at Abereiddy Bay, as in his locality (Norman's Kill) and in South Scotland. From his description, however, we gather that the branches of *D. serratulus* are straight from their origin, and are almost filiform throughout, definitions it is impossible to apply to those of the present species. The thecæ of his figured example are also of very different form, and greatly resemble those of *D. superstes*.

The more prominent characteristics of *Didymograptus euodus* are the small curved proximal portions of the branches, their extraordinary length and insensible augmentation in diameter, and the very distant peculiarly shaped hydrothecæ.

Loc. Lower Llandeilo, Abereiddy Bay.

DIDYMOGRAPTUS BIFIDUS, Hall, sp. Pl. XXXIII. figs. 8*a*–8*e*.

1865. *Graptolithus bifidus*, Hall, Grapt. Quebec Group, p. 73, pl. i. figs. 16–18, pl. iii. figs. 9, 10.

1868. *Didymograpsus bifidus*, Nich. Quart. Journ. Geol. Soc. vol. xxiv. p. 136.

1870. *Didymograpsus bifidus*, Nich. Ann. & Mag. Nat. Hist., ser. iv. vol. v. p. 346, fig. 7.

Branches from half an inch to one inch in length, very narrow at their origin, but gradually expanding to about a tenth of an inch or more in width, and more rapidly contracting towards their distal end, their dorsal margin being nearly straight and their ventral curved; diverging from each other at an angle of about 300 degrees near their origin, increasing to 340 degrees, which they maintain throughout their length; sicula slender, gradually tapering to a fine point; hydrothecæ from 32 to 36 to the inch, slightly curved, inclined to the axis of the branches at an angle of about 45 degrees, three or four times as long as wide, and free for about one fourth their length; apertural margin concave, forming an obtuse angle with the axis.

There occur in the St.-David's beds several forms of *Didymograptus*, in all of which the angle of divergence is so large that the ventral margins of the branches are parallel, or but slightly divergent. Most palæontologists hitherto have somewhat dubiously divided them between the two species *Didymograptus Murchisoni*, Beck, and *D. geminus*, His. There are, however, in reality not two, but four, tolerably distinct forms in this group, which embraces the *D. bifidus*, *D. indentus* (with var. *nanus*), *D. Murchisoni*, and *D. furcillatus* of the present memoir; and if *D. Murchisoni* and *D. geminus* are to be regarded as distinct species, the remaining types must also receive distinctive titles. The forms belonging to this group are certainly most intimately allied; and specimens are sometimes met with which point to a gradual transition between some of them; and the remaining blanks are almost filled in by foreign forms. It may consequently be found necessary at some future date to group them all in a single highly variable species. As each form of the group, however, can be easily recognized at a glance, and is characteristic of a definite portion of the succession in the St.-David's rocks and elsewhere, they may most conveniently be regarded in the meantime as distinct but closely allied species.

Hisinger's figure of *Prionotus geminus* (Lethæa Suecica, Supp., ii. tab. ii. fig. 3) shows us a diminutive form bearing wide branches with close-set denticles, and having a prominent sicula and arch-like axil. It approaches closest in its general features to the present species, but does not seem to be absolutely identical. The *Graptolithus geminus* of Scharenberg (Ueber Graptolithen, taf. i. figs. 1, 3, 4) is a very different species, and more nearly resembles our *Didymograptus furcillatus*.

Loc. Upper Arenig, Porth Hayog, Ramsey Island.

DIDYMOGRAPTUS INDENTUS, Hall, sp. Pl. XXXIII. figs. 7*a*–7*c*.

α.

1858. *Graptolithus indentus*, Hall, Rep. Geol. Surv. Canada for 1857, p. 128.

1865. *Graptolithus indentus*, Hall, Grapt. Quebec Group, p. 74, pl. i. fig. 20.

β.

Var. *nanus*, Lapw. Pl. XXXIII. fig. 7 *d*; Pl. XXXV. figs. 4 *a*–4 *c*.

1868. *Didymograpsus geminus*, Nich. (*non* His.), Quart. Journ. Geol. Soc. vol. xxiv. p. 124, pl. v. figs. 8, 9.

1870. *Didymograpsus geminus*, Nich. Ann. & Mag. Nat. Hist. ser. 4, vol. v. p. 346, fig. 6.

Branches slender, maintaining an almost equal width throughout, from one to two inches (or more) in length, diverging from each other at a primary angle of about 300 degrees, gradually incurving for the first quarter of an inch, and nearly parallel for the remainder of their length; sicula slender, acutely pointed; virgula very distinct; hydrothecæ from 20 to 25 to the inch, inclined to the axis at an angle of from 30 to 35 degrees, three times as long as wide, overlapping each other for about half their length; apertural margins straight, forming an angle of 90 degrees or less with the axis; denticles pointed, submucronate.

In addition to the typical form of this species as figured by Hall (Grapt. Quebec Group, pl. i. fig. 20), there frequently occurs a dwarf variety with very short branches and closely set denticles. It passes beyond the limits of the Upper Arenig as high as the Middle Llandeilo of Abereiddy Bay. It occurs abundantly in the highest beds of the Upper Arenig (Upper Skiddaw Slates) of the Lake district, and may appropriately be called var. *nanus*.

Loc. Typical form—Upper Arenig, Porth Hayog, Ramsey Island. Var. *nanus*—Upper Arenig, Llanvirn Quarry; Lower and Middle Llandeilo, Abereiddy Bay.

DIDYMOGRAPTUS MURCHISONI, Beck, sp. Pl. XXXV. figs. 2 *a*–2 *f*.

1839. *Graptolithus Murchisoni*, Beck, Murch. Silur. Syst. pl. xxvi. fig. 4.

1861. *Didymograpsus Murchisoni*, Baily, Quart. Journ. Geol. Soc. Dublin, vol. ix. pl. iv. figs. 1 *a*, *b*, *c*.

1869. *Didymograpsus Murchisoni*, Hopk. Journ. Quekett Micr. Club, vol. i. pl. viii. figs. 6 *a*, 6 *b*.

1870. *Didymograpsus Murchisoni*, Nicholson, Ann. & Mag. Nat. Hist. ser. 4, vol. v. p. 349, pl. vii. figs. 7, 7 *a*, 7 *b*.

Branches robust, from two to three inches in length, diverging from a large blunt sicula at a primary angle of about 320 degrees; curved at their origin, but almost immediately becoming straight and perfectly parallel; very narrow at their commencement and gradually expanding throughout to a maximum diameter of one sixth of an inch; hydrothecæ 20 to 25 to the inch, making an average angle of 45 degrees with the axis of the branch; apertural and outer margins concave, forming a very acute denticle.

The axillary portion of the polypary in adult and typical examples of this species is much broader than in any of the closely allied forms; and the sicula is proportionately stouter and shorter, rarely exceeding one tenth of an inch in length, and with its distal extremity either abrupt or obtusely rounded. The latter, however, is not an invariable characteristic, as pointed examples are sometimes met with. The general angle formed by the *ventral* margins of the branches near their common point of origin varies from 30 to 60 degrees. After freeing themselves from the broad curve of their proximal extremities, the branches become almost immediately straight and parallel, and so continue for the remainder of their length. In a few full-grown examples the distal portions of the branches gradually approximate until their ventral margins are in contact, or even slightly cross each other. Near the axil the hydrothecæ scarcely overlap each other at all, but lie almost parallel with the general line of direction of the branch. They gradually lengthen as they extend along the branch, increasing their angle of inclination first to 45 degrees and ultimately to about 90 degrees, and their length from one twentieth to one fifth of an inch. At the distal end of the branch they overlap each other for more than four fifths of their length. The apertural and outer margins are both concave. The resultant denticle is consequently very acute, and it is frequently prolonged into a slender spine.

Loc. Lower Llandeilo (lower and upper zones), Abereiddy Bay.

DIDYMOGRAPTUS FURCILLATUS, Lapw., sp. nov. Pl. XXXV. figs. 3 *a*–3 *d*.

1851. *Graptolithus geminus*, Scharenberg (*non* His.), Ueber Graptolithen, tab. i. figs. 1, 3 & 4.

Branches rigid, one and a half to two inches in length, curved at their commencement, but soon becoming straight, and ultimately including an angle of from 330 to 345 degrees; originally narrow, but slowly widening out to a point of maximum diameter and then rapidly contracting to their distal extremities; sicula short, pointed; hydrothecæ 24 or 25 to the inch, inclined at an average angle of 45 degrees; apertural margins almost straight, at right angles with the normal direction of the theca; denticles inconspicuous.

The axillary portion of the polypary in this well-marked form is narrower, and the sicula more pointed than in *D. Murchisoni*. The branches, in place of showing anything of that tendency to cross each other pointed out in that species, have the distance between them continually augmented, the ultimate ventral angle never being less than 15 degrees. The thecæ very slowly increase in length, angle of inclination, and amount of overlap, till they reach a point situate within the last third of the branch. Here they have a length of about one-eighth of an inch, are inclined at an angle of 45 degrees, and overlap each other for three fourths of their length. Beyond this spot they rapidly diminish in all these points, and the final thecæ are often very short and rudimentary. This peculiar disposition of the thecæ gives a remarkable curving outline to the ventral margin, and forms perhaps the chief characteristic of this species.

Loc. Lower Llandeilo (lower zone), Abereiddy Bay.

Genus TETRAGRAPTUS, Salter.

TETRAGRAPTUS QUADRIBRACHIATUS, Hall, sp. Pl. XXXIII. figs. 9 *a*, 9 *b*.

1858. *Graptolithus quadribrachiatus*, Hall, Rep. Geol. Surv. Canada for 1857, p. 125.

1863. *Tetragrapsus crucialis*, Salter, Quart. Journ. Geol. Soc. vol. xix. p. 137, fig. 8 *b*.

1865. *Graptolithus quadribrachiatus*, Hall, Grapt. Quebec Group, p. 91, pl. v. figs. 1–5, pl. vi. figs. 5, 6.

1874. *Tetragraptus quadribrachiatus*, Ether. jun. Ann. & Mag. Nat. Hist. ser. 4, vol. xiv. p. 3, pl. iii. figs. 5–8.

Branches straight or nearly so [springing bilaterally and symmetrically from either side of a short slender funicle], gradually increasing in width from about one twentieth of an inch at their origin to one tenth at their extremities; virgula very distinct; periderm well marked, narrow; hydrothecæ from 20 to 24 to the inch, inclined to the axis at an angle of 30° or 40°, about four times as long as broad, and free for one third to one half their length, transversely striated, and slightly expanding towards their extremities; apertural angle 95° to 100°, margin nearly straight.

Associated with the other species of this genus here described there occur single branches having all the characters of this species, and agreeing precisely with Hall's description. In one or two specimens the branches are broken off, so as just to show a small portion of the funicle, but barely sufficient to determine the form to be a *Tetragraptus*. The characters shown by the isolated branches, however, are sufficiently distinctive.

Loc. Middle Arenig, Whitesand Bay.

TETRAGRAPTUS SERRA, Brongniart, sp. Pl. XXXIII. fig. 10.

1828. *Fucoides serra*, Brongn. Hist. Veg. Foss. vol. i. p. 71, pl. vi. figs. 7, 8.

1851. *Graptolithus Murchisoni*, Bœck (in part), Bemärkn. Grapt. p. 10, pl. ii. fig. 30.

1852. (?) *Cladograpsus serra*, Geinitz, Die Graptolithen, p. 30, taf. v. figs. 32–35.

1858. *Graptolithus bryonoides*, Hall, Rep. Geol. Surv. Canada for 1857, p. 126.

1863. *Tetragrapsus bryonoides*, Salter, Quart. Journ. Geol. Soc. vol. xix. p. 137, fig. 8*a*.

1865. *Graptolithus bryonoides*, Hall, Grapt. Quebec Group, p. 48, pl. iv. figs. 1–11.

1868. *Didymograpsus bryonoides*, Carr. Geol. Mag. vol. v. p. 129.

1874. (?) *Tetragraptus bryonoides*, Ether. jun. Ann. & Mag. Nat. Hist. ser. 4, vol. xiv. p. 2, pl. iii. figs. 1–4.

Branches connected by a short funicle, in the centre of which the sicula is usually seen as a minute triangular process, diverging at various angles, narrow at their origin, but soon acquiring their full width of from one tenth to one eighth of an inch, which they maintain to near their distal extremity, which is abruptly rounded and occupied by the partially developed hydrothecæ; hydrothecæ from 20 to 24 to the inch, inclined to the axis at an angle of 40° or 50°, four times as long as wide, free for about one fourth their length, and slightly recurved towards their distal end; margin of aperture concave, making an obtuse angle with the axis of the branch.

There can be little doubt, as Professor Hall has himself stated, that his *Graptolithus bryonoides* is identical with the *Fucoides serra* of Brongniart; and our St.-David's and Skiddaw Arenig forms answering to the above description are also referable to the same; but some specimens figured as *Tetragraptus bryonoides* seem to be specifically distinct, and should perhaps be referred to the species I have here described as *T. Halli*. In the absence of sufficiently definite descriptions and sufficiently accurate figures this point cannot be decided; and we would therefore provisionally place under *T. serra* all the forms to which the specific name *bryonoides* has been applied.

Loc. Middle Arenig, Whitesand Bay.

TETRAGRAPTUS HALLI, Hopk., sp. nov. Pl. XXXIII. figs. 11*a*, 11*b*.

Branches incurved, springing almost immediately from a large pointed sicula, from which they diverge at various angles, at first rapidly, then gradually expanding for the greater part of their length, and again gradually contracting towards their extremities, their extreme width being one fifth of an inch; hydrothecæ from 25 to 30 to the inch, inclined to the axis of the branches at an angle of from 20° to 30°, from five to six times as long as wide, with only their slightly mucronate extremities free, and decidedly curved outwards throughout their entire length; apertural margin concave.

We have several specimens, more or less perfect, all of which show one distinctive character—the thecæ are scarcely perceptible, appearing only as submucronate denticles extending very slightly beyond the general margin of the ventral side of the branches. The curved lines of division can only just be made out in one or two of the better-preserved specimens. Two branches only are usually seen.

It is possible, as mentioned above, that some of the specimens which have been referred to *Tetragraptus serra* may be of this species; but as the two forms are at present only known to occur on the same horizon, this cannot create any confusion. It will be unnecessary to draw a comparison between the two species, as a glance at the figures will at once show their distinctive characters.

We name this species after Professor James Hall, to whose classical work on the Graptolites of the Quebec Group we have had so frequently to refer.

Loc. Middle Arenig, Whitesand Bay.

TETRAGRAPTUS HICKSII, Hopk., sp. nov. Pl. XXXIII. figs. 12*a*–12*d*.

Branches slender, decidedly recurved, from an inch to an inch and a half in length, springing almost immediately from a minute obtusely pointed sicula, from which they diverge at various angles; very gradually expanding near their origin, but more rapidly near their extremities, their maximum width being one sixteenth of an inch; hydrothecæ about 12 to the inch, three times as long as wide, their outer margins concave, free for the greater part of their length, and inclined to the axis of the branches at an angle of about 30°; apertural angle 60° to 90°.

In its slender recurved branches and acutely pointed hydrothecæ this species is widely separated from all the others of its genus except *T. fruticosus*, Hall, from which it differs in its more slender and often widely divergent branches, in its minute sicula, and in its more pointed and more distant hydrothecæ.

It occurs *in profusion*, though usually very badly preserved, and most frequently in separated branches, a few feet lower than the other species of the genus here described. It was discovered by Mr. Hicks, who was the first to recognize its distinctness from *T. fruticosus*, and after whom we have therefore much pleasure in naming it.

Loc. Middle Arenig, Whitesand Bay.

Genus CLEMATOGRAPTUS, Hopkinson, gen. nov.

(Derivation: κλῆμα, a branch; γράφω, I write.)

Polypary compound, bilaterally subsymmetrical, consisting of numerous (never less than than thirty-two) normally simple closely approximating branches, radially disposed, arising singly or in groups from both margins of an irregularly and repeatedly branching funicle; hydrothecæ of the type of those of Dichograptus.

This genus is nearly related to *Loganograptus* and *Clonograptus*. From the former it differs in the much greater number and inequality of the primary divisions of the funicle, and from the latter in the manner in which the division and subdivision of the funicle is carried out and the branches ultimately given off. In *Clonograptus* the compound funicle invariably branches and rebranches in a regularly dichotomous manner, each new division being attained by exact and equal bifurcation, the consecutive bifurcations at the same time being separated by comparatively wide and regular intervals. In *Clematograptus*, on the contrary, the subdivision of the funicle is carried out in a very irregular manner, the branches being finally given off at inconstant but pretty close intervals, either along one or both sides of the branching funicle, or even in dense groups. The rigid spreading polypary in *Clonograptus* is thus remarkable for the symmetrical arrangement of its parts, while in this respect the closely set but lax *Clematograptus* is correspondingly unique in its irregularity.

The only undoubted species of *Clematograptus* known at present are the *C. implicatus* of this memoir, and the *C.* (*Graptolithus*) *multifasciatus* of Prof. Hall.

CLEMATOGRAPTUS IMPLICATUS, Hopk., sp. nov. Pl. XXXIV. fig. 1.

Loganograpsus (?) *implicatus*, Hopk. Brit. Assoc. Report, 1872.

Branches very numerous, slender, flexuous, arising from a very irregularly repeatedly branching funicle, the divisions of which are as flexuous and irregularly disposed as the branches.

We have only a single specimen of this species, probably of a young individual; for there is scarcely more than the funicle seen, slight traces of hydrothecæ being visible only at the extremities of some of its subdivisions. The funicle branches most irregularly, some of its divisions not bifurcating more than once, while others give off branches repeatedly at distances of a quarter of an inch or less from each other. It covers a space of about an inch square. The branches ultimately given off are at least sixty in number.

From the *Clonograptus* (*Graptolithus*) *multifasciatus* of Hall, the only other species of the genus known, *C. implicatus* differs in its more slender, more flexuous, and more frequently branching funicle, and in the greater number of branches to which it gives origin.

Loc. Middle Arenig, Whitesand Bay.

Family NEMAGRAPTIDÆ, Hopkinson.

Genus NEMAGRAPTUS, Emmons.

NEMAGRAPTUS CAPILLARIS, Emmons. Pl. XXXIV. figs. 2*a* & 2*b*.

Nemagraptus capillaris, Emmons, American Geology, vol. i. pl. i. fig. 7.

Principal branches compound, thread-like, and highly flexuous, diverging in approximately opposite directions from a central point, and giving off a few similar short and simple secondary branches at subregular intervals, from one margin only; sicula and hydrothecæ unknown.

This is in many respects a most extraordinary form. The highly flexuous, smooth, and excessively slender branches, offering no trace of the marginal denticles so characteristic of the branching Rhabdophora, compose a polypary whose general appearance is strikingly distinct from that of any other known species of Graptolite. Our examples, which lie in a tangled group of whitish threads imbedded in a dark greenish grey matrix, admit of immediate identification with Emmons's species (Amer. Geol. *loc. cit. suprà*). Neither his specimens nor our own offer any conclusive evidence of the manner in which the two main branches originate from the sicula. Judging from the distribution of the branchlets, the only view which seems probable is that the central branchlet is formed by the prolongation of the minor extremity of the sicula, while the main branches both originate immediately at its major extremity, as in the greater proportion of the siculate Rhabdophora. In the two known forms which most closely approach the present species in general appearance, viz. *Nemagraptus* (?) *fragilis*, Nich., sp., and *Leptograptus capillaris*, Carr., sp., the main branches also originate from the major end of the sicula; and in the last-named species the minor extremity frequently develops a central branch. If this be the mode of growth in the present species, it differs most notably from that which obtains among the species provisionally referred to

Nemagraptus which occur in South Scotland, and also in those which belong to the genus *Cœnograptus* of Hall. In all these the primary branches originate from approximately opposite points midway along the sicula, which forms a remarkable "radicular" or proximal *bar* in the adult organism, a feature unknown in the Rhabdophora outside the limits of these two most intimately allied genera.

In another respect, also, the present examples unfortunately resemble those figured by Dr. Emmons. They show nothing that can be referred to the denticles or hydrothecal apertures, beyond a certain ill-defined crenulation of the margins of some of the branchlets. This, however, is the rule both in *Nemagraptus* and *Cœnograptus*. The latter especially, though both its primary and secondary branches are furnished with hydrothecæ throughout the whole of their extent, rarely affords conclusive evidence of their presence on the chief branch until the last branchlet has been thrown off. This circumstance was pointed out by Dr. Emmons in connexion with *Nemagraptus*; and Professors Hall and Nicholson both make the supposed non-polypiferous character of the proximal portions of the main branches the chief characteristic of the genus *Cœnograptus*.

Loc. Upper Arenig, Llanvirn Quarry.

Family DICRANOGRAPTIDÆ, Lapworth.

Genus Dicellograptus, Hopkinson.

Dicellograptus moffatensis, Carruthers, sp. Pl. XXXIV. figs. 3 *a*, 3 *b*; Pl. XXXV. figs. 5 *a*, 5 *b*.

1858. *Didymograpsus moffatensis*, Carr. Trans. R. Phys. Soc. Edin. p. 469, fig. 3.

1859. *Graptolithus divaricatus*, Hall, Pal. N. York, vol. iii. pt. 1, p. 514, figs. 1–4.

1870. *Didymograpsus divaricatus*, Nicholson, Ann. & Mag. Nat. Hist. ser. 4, vol. v. p. 350, pl. vii. figs. 4, 4 *a*.

1871. *Dicellograpsus moffatensis*, Hopk. Geol. Mag. vol. viii. p. 25, pl. i. figs. 4 *a*, 4 *b*.

Branches somewhat rigid and slightly curved, diverging from each other at an angle of from 30° to 90°; axil furnished with a well-marked radicle and two short lateral spines; sicula short and stout, scarcely ever visible; hydrothecæ 20 to 25 to the inch, isolated and strongly incurved for the last third of their length; interspaces very oblique, usually compressed to a mere slit.

The specimens of this species, collected from the Llandeilo beds of Abereiddy Bay, are very indifferently preserved, and it is scarcely possible to make out more than the general characteristic shape of the polypary. They all belong to the well-marked variety *divaricatus* of Professor Hall, in which the branches are straighter and more rigid than in the typical form. A single specimen only has been procured from the Upper Arenig shales of Llanvirn; and this, in some of its characters, points in the direction of the very distinct *D. Forchhammeri*. This unique specimen is of very great interest, as it is the earliest example yet detected of the family of the Dicranograptidæ.

Loc. Upper Arenig, Llanvirn Quarry. Middle Llandeilo, Abereiddy Bay.

Family DIPLOGRAPTIDÆ, Lapworth.

Genus CLIMACOGRAPTUS, Hall.

CLIMACOGRAPTUS CÆLATUS, Lapw., sp. nov. Pl. XXXV. figs. 8*a*–8*e*.

Length from one inch to one inch and a half, maximum width one eighth of an inch, ventral margins normally parallel, but rapidly converging towards the proximal extremity, which is abrupt and furnished with two short horizontal spurs; virgula stout, greatly prolonged both proximally and distally; hydrothecæ 20 to 24 to the inch, apertural margins concave, very oblique; interspaces deep, and occupying about two fifths of the ventral margin.

The prolonged proximal portion of the virgula frequently attains an extraordinary length in this species, sometimes equalling that of the polypary itself. It is often expanded a little in the centre of its length, but it never forms any thing deserving the title of terminal vesicle. The radicular spurs are stout and short, and are often very rudimentary. Perhaps the most marked characteristic of the species is afforded by the peculiar shape and direction of the interspaces, the proximal boundary of each, instead of being horizontal as in all the more recent *Climacograpti*, makes an angle of about 60° with the general axis of the polypary. This is in all likelihood due to the circumstance that the section of the uncompressed polypary was somewhat concavo-convex, the distal end of each theca at the same time being a little introverted, as in the subgenus *Glyptograptus*. A similar appearance is noticeable in the following species (*C. confertus*).

Loc. Lower Llandeilo, Abereiddy Bay (lower zone).

CLIMACOGRAPTUS CONFERTUS, Lapw., sp. nov. Pl. XXXIV. figs. 4*a*–4*f*.

Length about one inch, maximum width one twelfth of an inch, margins parallel; proximal extremity pointed, furnished with a short radicle only; hydrothecæ about 40 to the inch; interspaces subtriangular, slightly oblique, and occupying about one third of the ventral margin.

The distinguishing peculiarities of this small species are its diminutive size, the absence of distal prolongation of the virgula, and the remarkable form and proportions of the interspaces. The shape of the last in casts of this form is strikingly distinct from that of almost every other described species of *Climacograptus*, and shows that in their uncompressed state the hydrothecæ must have greatly resembled, both in their disposition and in their general form, those in the subgenus *Glyptograptus*. A further distinction consists in the occasional protrusion of the epiderm of each hydrotheca immediately at its commencement, thus forming a rudimentary proximal spine.

Loc. Upper Arenig, Porth Hayog, Ramsey Island.

Genus Diplograptus, M^c^Coy.

Diplograptus dentatus, Brongniart, sp. Pl. XXXIV. figs. 5*a*–5*k*.

1828. *Fucoides dentatus*, Brongniart, Hist. Vég. Foss. pl. vi. figs. 9–12.
1865. *Diplograptus pristiniformis*, Hall, Grapt. Quebec Group, p. 110, pl. xiii. figs. 15, 16, 17.
1867. *Diplograpsus pristiniformis*, Nicholson, Quart. Journ. Geol. Soc. vol. xxiv. p. 140, pl. v. figs. 14, 15.

Length one inch to one inch and a quarter, maximum width one tenth of an inch; ventral margins normally parallel, converging near the rounded proximal extremity, which is furnished with a strong pointed radicle; virgula stout, distally prolonged; hydrothecæ 22 to 30 to the inch, making a small angle with the general line of the septum; outer margin of each convex, apertural margin deeply concave when compressed, and sometimes provided with a single median spine which is directed distally.

The compressed polypary in this species presents a great variety of appearances, dependent upon age or direction of compression. In the normal (*reverse*) aspect the deeply concave apertural margins and the broadly rounded outer edges of the hydrothecæ are very characteristic. Examples presenting the opposite (*obverse*) view cannot be distinguished from young specimens of *D. foliaceus*, Murch.; while those offering the *ventral* or scalariform aspect are inseparable from *Climacograptus*. Almost invariably the well-marked radicle is the only visible proximal appendage; but there is evidence that it was sometimes accompanied by two very minute lateral spines. The distinct apertural spines can be seen only in the normal aspect of the polypary, and are visible only in very rare cases.

Loc. Upper Arenig, Porth Hayog, Ramsey Island, and Llanvirn Quarry.

Diplograptus foliaceus, Murchison, sp. Pl. XXXV. figs. 7*a*–7*g*.

1839. *Graptolites foliaceus*, Murch., Silurian System, pl. xxvi. fig. 3.
1847. *Graptolithus pristis*, Hall, Pal. N. York, vol. i. pl. lxxii. figs. 1*d* to 1*r*.
1847. *Graptolithus secalinus* (Eaton), Hall, *loc. cit.* figs. 2*a*, *b*, *c*.

1850. *Diprion foliaceus*, Harkness, Quart. Journ. Geol. Soc. vol. vii. p. 64, pl. i. figs. 13*a*, *b*, *c*.
1852. *Diplograpsus foliaceus*, Geinitz, Graptolithen, taf. i. figs. 29, 30.
1859. *Graptolithus pristis*, Hall, Pal. New York, vol. iii. Supplement, p. 516.
1866. *Diplograpsus barbatulus*, Salter, Mem. Geol. Surv. vol. iii. pl. xi. A. figs. 1 *e*, *d*.
1868. *Diplograpsus pristis*, Carruthers, Geol. Mag. vol. v. pl. v. figs. 13 *a*, *b*, *c*, *d*.
1869. *Diplograpsus pristis*, Hopk., Journal Quekett Micros. Club, vol. i. pl. viii. fig. 11 *a*.
1872. *Diplograpsus pristis*, Nicholson, Monograph British Graptolitidæ, pt. i. figs. 22, 26, 50.

Length from one to three inches, average breadth about one sixth of an inch, margins parallel distally, converging towards the proximal extremity, which is normally furnished with a radicle and two marginal spurs; virgula very distinct, greatly prolonged distally; hydrothecæ 18 to 30 to the inch, making a very small angle with the general axis of the polypary; apertural margin oblique; apertural spine single, frequently wanting.

It is almost impossible to frame a diagnosis sufficiently broad to include the extreme varieties of this protean form. The foregoing description embodies all the more constant characteristics of the species. The features which seem to be least variable in British examples are the great length of the distal prolongation of the virgula, and the very small angle included between the outer margin of the theca and the general line of the direct septum. The former is never less than half the length of the polypary, and the latter oscillates between 15° and 20°. The specimens we have collected at Meadowtown, Shropshire (the locality which afforded the examples on which this species was originally founded), show a very stunted variety, which rarely exceeds an inch in length, and bears above thirty hydrothecæ to the inch. There is little room for doubting its identity with the form described and figured by Murchison and Sowerby as *Graptolithus foliaceus*. The same form, together with *D. secalinus* and several other varieties much further removed in general aspect from the typical *D. foliaceus*, occur in association in South Scotland and elsewhere, and are all connected together by intermediate forms.

The variety which occurs at Abereiddy Bay appears to be identical with the *Graptolithus secalinus* of Eaton, as figured by Professor Hall in his 'Palæontology of New York,' vol. i. pl. 1. figs. 2 *a*, *b*, *c*. It differs from the majority of the later varieties in the marked parallelism of the greater portion of the ventral margins, and in the compact arrangement of the thecæ, which are closely appressed to the periderm, the denticles projecting very slightly beyond the general boundary of the fossil. In our examples the proximal end of the polypary is usually broadly rounded, and the primary processes, though invariably present, are rarely very conspicuous. Some very long examples point in the direction of the more recent varieties, the distal portions of the hydrothecæ being somewhat sacculate, and the denticles consequently more rounded and projecting.

Loc. Lower and Middle Llandeilo, Abereiddy Bay.

DIPLOGRAPTUS TRICORNIS, Carruthers. Pl. XXXV. figs. 6*a*, 6*b*.

1855. *Diplograpsus tricornis*, Carruthers, Trans. R. Phys. Soc. Edin. p. 468, fig. 2.

1859. *Graptolithus marcidus*, Hall, Pal. N. York, vol. iii. p. 514, figs. 1–3.

Length from one inch to one inch and a quarter, with an average diameter of one twelfth of an inch; margins strictly parallel; proximal extremity abrupt, furnished with a well-marked radicle and two similar diverging spines; virgula slender, distally prolonged; hydrothecæ 25 to the inch, making an exceedingly small angle with the general axis of the polypary; edge of aperture without distinct ornament, rarely projecting outside the lateral margin.

The few specimens collected belong to a very diminutive variety of this species; and although they are in a fair state of preservation, the foregoing characters are all that can be satisfactorily made out. The three distinctive proximal processes and the parallel and slightly waved ventral margins of the polypary are well exhibited; and in some examples the margin of the thecal aperture is visible as a short transverse line running partly across the periderm. The virgula is always prolonged distally; it is very slender, and affords no evidence of ever having been furnished with that terminal fusiform appendage so frequent in some later varieties.

Loc. Lower and Middle Llandeilo, Abereiddy Bay.

Family PHYLLOGRAPTIDÆ, Lapworth.

Genus PHYLLOGRAPTUS, Hall.

PHYLLOGRAPTUS STËLLA, Hopk., sp. nov. Pl. XXXIV. fig. 6.

Brit. Assoc. Report for 1872.

General outline nearly circular, slightly wider than long; radicle minute, scarcely perceptible; hydrothecæ about 40 to the inch, very much curved, their angle of divergence from the general axis increasing from about 20° to 80° from their origin to their apertures; apertures concave, strongly mucronate.

This pretty little star-like species differs from all others of its genus in its broadly circular form, and in the number of thecæ in the inch. We have found a single specimen only. Its length is nearly three tenths of an inch; and its width slightly exceeds three tenths. Two of its contiguous series of hydrothecæ only are shown; and at their line of junction they appear to have split slightly apart, exposing a slender rod, on either side of which there is a free space, apparently indicating that the walls of the thecæ did not extend quite to the centre of the organism. This seems to prove the presence of a virgula in the genus *Phyllograptus*, and that its hydrothecæ, in each series, freely communicate with one another. No evidence of such a structure, however, has been detected in the specimens of this genus from the Quebec Group; nor has such been furnished by the more imperfectly preserved specimens from the Skiddaw Slates.

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

Section RETIOLOIDEA, Lapworth.

Family GLOSSOGRAPTIDÆ, Lapworth.

Genus GLOSSOGRAPTUS, Emmons.

GLOSSOGRAPTUS CILIATUS, Emmons. Pl. XXXIV. figs. 7*a* & 7*b*.

1855. *Glossograptus ciliatus*, Emmons, American Geology, vol. i. p. 108. pl. i. fig. 25.

Subfusiform, with broadly rounded extremities, about one inch in length, and having a maximum diameter of one eighth of an inch; virgula and lateral spurs invisible; hydrothecæ 25 to the inch; apertural spines placed perpendicularly to the line of the ventral margin at their point of origin, stout, slightly arcuate, and about one tenth of an inch in length.

The fragment figured, which is the only specimen of this species obtained from the St.-David's beds, has almost exactly the same number of hydrothecæ to the inch as are found in the typical example given by Dr. Emmons. Only a single row of apertural spines is apparent on each margin; and the two longitudinal series of lateral processes, characteristic of this genus and its very intimate ally *Retiograptus* of Professor Hall, are wholly invisible. The great rigidity and extraordinary length of the apertural spines form the chief peculiarity of this species. Emmons's figure shows exactly the same relative development of these appendages. They are, however, figured as being slightly narrower and less rigid than they are in our example, while the polypary itself is proportionally broader.

Loc. Upper Arenig, Llanvirn Quarry.

Family GLADIOGRAPTIDÆ, Lapworth.

Genus TRIGONOGRAPTUS, Nicholson.

TRIGONOGRAPTUS ENSIFORMIS, Hall, sp. Pl. XXXIV. figs. 8*a*–8*c*.

1851. *Graptolithus ensiformis*, Hall, Rep. Geol. Surv. Canada for 1850, p. 133.

1865. *Retiolites ensiformis*, Hall, Grapt. Quebec Group, p. 114, pl. xiv. figs. 1–5.

About half an inch in length, attaining a maximum breadth of one tenth of an inch about the centre of its length, the margins converging towards both extremities, each of which is obtusely pointed and wholly devoid of ornament; virgula central, straight; hydrothecæ alternating, about 30 (?) to the inch.

This brief description includes all the characters it is possible to discover in the very badly preserved examples of this species which occur in the shales of Ramsey Island. The hydrothecæ are invisible directly; but their number and positions are deduced from the presence and place of some regular but almost invisible depressions in the line of the otherwise perfectly plain lateral margins of the polypary. What appears to be the virgula is visible as a straight but very faint longitudinal stain running exactly down the centre of one of the examples. The peculiar subfusiform shape of the polypary in this species comes out clearly in a few specimens; others are truncate at their distal extremities, and may possibly be diminutive examples of the species next to be described.

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

TRIGONOGRAPTUS TRUNCATUS, Lapw., sp. nov. Pl. XXXIV. figs. 9*a*–9*d*.

Half an inch to one inch in length, with an obtusely rounded proximal extremity, attaining a maximum width of one sixth of an inch at its distal end, which is limited by a perfectly straight line; ventral margins plain, slightly curved; virgula undulating (?); hydrothecæ 30 or more to the inch; epiderm very thin, but apparently continuous.

We name this species with some doubt, as the surface characters of the polypary are so very obscure. The feature chiefly relied upon in support of its specific distinctness is the very peculiar form of the polypary. Several examples have been obtained, and the general shape and proportions are very similar in all. The proximal extremity is broadly rounded; and there is a continual increase in diameter throughout, the maximum width being attained at the distal extremity, where the polypary is abruptly terminated in a perfectly straight line. There is, however, a greater proportional expansion about the middle of the polypary; and the ventral margins are consequently a little curved. The undulation of the virgula is a doubtful feature; neither is it possible to be certain of the number and inclination of the thecæ.

The great breadth and straight distal end of the polypary in this form clearly separate it from the foregoing species. It approximates closely, in some respects, to *Trigonograptus lanceolatus* of Nicholson; but its form and size are very different.

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

Suborder *CLADOPHORA,* Hopkinson.

Section Dendroidea, Nicholson.

Family PTILOGRAPTIDÆ, Hopkinson.

Genus Ptilograptus, Hall.

Ptilograptus cristula, Hopk., sp. nov. Pl. XXXVI. figs. 2*a* & 2*b*.

Brit. Assoc. Report for 1872.

Very slender, bipinnate; stem waved or zigzagged, about the same thickness as the branches; primary branches alternate, diverging from the main stem at an angle of about 45°, and occasionally giving off short secondary branches in a similar manner and diverging at the same angle; hydrothecæ not perceptible.

The only specimens we have are probably merely fragments; and therefore this description can only be considered provisional. The characters by which the species may be distinguished from others are its delicate habit, somewhat sparse wide-spreading branches, and short branchlets, which also diverge widely from the branches from which they spring.

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

Ptilograptus Hicksii, Hopk., sp. nov. Pl. XXXVI. figs. 1*a* & 1*b*.

Brit. Assoc. Report for 1872.

Slender, tripinnate; stem slightly waved, thicker than the branches; primary branches, alternate, diverging from the main stem at an angle of from 35° to 40°, and occasionally giving off secondary branches, which form a very slight angle (about 15°) with the primary ones, the secondary branches again giving off slender branchlets in a similar manner; hydrothecæ about 40 to the inch, narrowly cup-shaped in form, and with minute circular apertures.

In its single, strong central stem, giving off from either side more slender plumose branches, the branchlets of which soon become parallel and densely crowded, this species differs much from any before described, more nearly approaching an undescribed form from the Ludlow rocks of Herefordshire than any Arenig species.

The specimen figured was the first Graptolite found in the Arenig rocks of Ramsey Island, being exposed by Mr. Hicks on breaking open a piece of shale picked up almost immediately on landing at the spot from which all our specimens from the Lower Arenig rocks of this island have been obtained. The specific name given to it is therefore peculiarly appropriate.

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

PTILOGRAPTUS ACUTUS, Hopk., sp. nov. Pl. XXXVII. figs. 1*a* & 1*b*.

Slender, frequently branched, the branches simply pinnate, forming only a small angle with each other, slightly waved and scarcely thicker than the branchlets; branchlets or pinnæ alternate, flexuous, from half to three quarters of an inch in length, diverging from the primary branches at a small angle (usually 30° to 40°); hydrothecæ 18 to the inch, forming distinct, distant, acutely pointed denticles with a slightly concave outer margin; apertural angle acute.

In its mode of branching this species somewhat resembles *Ptilograptus plumosus*, Hall; but the branches bifurcate more acutely, and are scarcely, if at all, thicker than the pinnæ they support. The hydrothecæ are quite unlike those of any species of *Ptilograptus* yet figured. They so nearly resemble, however, those of *Monograptus acutus*, Hopk., that we have given to this unique form the same specific name.

This species is the only *Ptilograptus* known to occur in the Llandeilo formation.

Loc. Lower Llandeilo, Abereiddy Bay (lower zone).

Family CALLOGRAPTIDÆ, Hopkinson.

Genus DENDROGRAPTUS, Hall.

DENDROGRAPTUS FLEXUOSUS, Hall. Pl. XXXVI. figs. 3*a*–3*d*.

1865. *Dendrograptus flexuosus*, Hall, Grapt. Quebec Group, p. 127, pl. xvii. figs. 1, 2.

Broadly expanding, usually covering a space about an inch and a half square; branches slender, flexuous, springing from a short robust common stem, bifurcating more or less regularly and diverging equally, forming at first a considerable angle with each other, but soon becoming nearly parallel, gradually lessening in width from their origin to their extremities; hydrothecæ about 30 to the inch.

This species, which is pretty well represented in the St.-David's beds, is at once recognized by its widely divergent form and slender flexuous branches.

One of the specimens figured shows, at its proximal end, a process which may represent the hydrorhiza of the recent Thecaphora, the main stem being here greatly widened out as if for attachment. Branches are soon given off, the outer ones on each side bending outwards with a curvature that brings round the numerous slender branchlets to which they give origin, so that these two widely divergent portions of the Graptolite are again brought together, the central portion not being perceptible beyond the first or primary branches. In this example (fig. 3 *b*) the branches diverge from each other at a wider angle than usual; and it may possibly prove to be a distinct species, to which the specific name *recurvus* might be given; it is here only regarded as a variety. It occurs associated with the normal form in the quarry near Shelve Church before referred to (*vide* p. 636).

Loc. Lower Arenig, Road Uchaf, Ramsey Island (both forms). Middle Arenig, Whitesand Bay (normal form only).

DENDROGRAPTUS PERSCULPTUS, Hopk., sp. nov. Pl. XXXVI. figs. 4*a*–4*d*.

Diffuse and irregular in form, frequently and somewhat regularly branched; branches robust, maintaining a width of about one fortieth of an inch throughout, gently undulating, and diverging only slightly from each other; hydrothecæ about 20 to the inch, delicately chiselled or fluted longitudinally on all sides, expanding slightly towards their distal ends, and curving so that their apices project slightly beyond the general margin of the ventral side of the branches, the dorsal side being here slightly indented, giving the branches an articulated appearance.

Of this beautifully sculptured species we have only a single specimen. Its length is about two inches, and its breadth an inch and a half. It is in a much better state of preservation than any other dendroid Graptolite we have found in the St.-David's rocks, Arenig or Llandeilo; and it owes its perfect preservation to its conversion into iron pyrites, a small portion only being covered by the white film which obscures the structure of almost every Graptolite we have obtained from the Lower Arenig rocks.

The only species to which *Dendrograptus persculptus* bears any resemblance is Hall's *D. striatus*; but the resemblance is only superficial, as a comparison of the figures and descriptions of the two species will show.

Loc. Lower Arenig, Whitesand Bay.

DENDROGRAPTUS ARBUSCULA, Hopk., sp. nov.. Pl. XXXVI. figs. 5*a* & 5*b*.

1873. *Dendrograpsus arbuscula*, Salter, MS., Catalogue Cambr. and Silur. Foss. in Cambridge Museum, p. 21.

About half an inch in length, very slightly branched, branches undulating, extremely slender, scarcely diverging at all from each other; hydrothecæ from 50 to 60 to the inch, cup-shaped in form, twice as wide at their distal as at their proximal end, their maximum width not exceeding one sixtieth of an inch, by their rapid expansion giving the branches an articulated appearance.

This species was first discovered by Mr. Hicks some years ago in the lower part of the Arenig rocks in Whitesand Bay, and the specimen in the Cambridge Museum, collected by him, was named *Dendrograptus arbuscula* by Mr. Salter; but the species has not until now been described or figured. All our specimens are preserved differently from any other species in these rocks, being simply impressions on the surface of the shale.

Fig. 5*a* is from an original specimen collected by Mr. Hicks in 1865.

Loc. Lower Arenig, Road Uchaf, Ramsey Island, and Whitesand Bay. Middle Arenig, Whitesand Bay (Camb. Mus.).

DENDROGRAPTUS DIVERGENS, Hall. Pl. XXXVI. figs. 6*a* & 6*b*.

1865. *Dendrograptus divergens*, Hall, Grapt. Quebec Group, p. 129, pl. xvii. figs. 3, 4.

Narrowly cup-shaped in form, usually of minute size; branches slender, bifurcating at frequent regular intervals, diverging very widely from each other at first, but soon curving inwards so as to become almost, and frequently quite, parallel; considerably thickened at their points of bifurcation.

A few specimens, showing the above characters only, have been found. In their general aspect, and in the regularity of the bifurcation of the branches, these specimens agree with Hall's figures; but the angle of divergence of the branches is not quite so great as in the example figured by him from the Quebec Group, and the thecæ cannot be made out. Hall, however, says that in his specimen the thecæ "are only determined by indentations in the shale."

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

DENDROGRAPTUS (?) DIFFUSUS, Hall. Pl. XXXVI. figs. 7*a* & 7*b*.

1865. *Dendrograptus*? (*Callograptus*?) *diffusus*, Hall, Grapt. Quebec Group, p. 132, pl. xviii. figs. 1–3.

Diffuse and irregular in form; branches strong, bifurcating frequently and irregularly, and bending slightly at each bifurcation; surface irregularly corrugated and marked with minute indentations, about 36 to the inch, which indicate the apertures of the hydrothecæ.

This species, in its mode of branching, and in its general aspect, is a true *Dendrograptus*; but its thecæ are quite unlike those of the typical forms of this genus, being indicated only by minute indentations, as in the genus *Callograptus*. In the specimen figured, however, where these indentations are not seen, the corrugations appear occasionally to be discontinuous or transversely jointed, thus somewhat resembling the thecæ of *Dendrograptus*, which they probably represent. These appearances, however, are not sufficiently defined to be represented in the figures.

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

DENDROGRAPTUS RAMSAYI, Hopk., sp. nov. Pl. XXXVI. figs. 2*a* & 2*b*.

Diffuse and irregular in form, branching at irregular usually somewhat distant intervals; branches flexuous, very gradually decreasing in width from about one twelfth of an inch near their origin to one hundredth at their extremities, irregularly striated longitudinally, diverging very slightly from each other, and occasionally giving off very short spine-like branchlets; hydrothecæ about 40 to the inch, producing slightly projecting, rounded denticles, when compressed laterally, and showing minute circular depressions (their apertures) when compressed with the ventral side upwards.

This very distinct species is chiefly remarkable for the short spinous processes which are here and there given off from the branches, sometimes seeming to be unquestionably true branchlets, sometimes scarcely more prominent than the hydrothecæ. The branches are sometimes entire, curving gracefully in varying directions for half an inch or more of their length; and less frequently they re-branch several times within this distance. A few of the laterally compressed thecæ show a subquadrangular impression, about a twentieth of an inch in diameter, the outline of which is alone defined. These impressions may possibly be merely owing to the collapse of the thecæ after the removal of the hydranths they have contained.

Dendrograptus fruticosus, Hall, and *D. serpens* seem to be its nearest allies.

We name it after Professor Ramsay, F.R.S., Director of the Geological Survey of Great Britain, who, when mapping this district for the Survey more than thirty years ago, discovered Graptolites for the first time in the locality in which it occurs.

Loc. Lower Llandeilo, Abereiddy Bay (higher zone).

DENDROGRAPTUS SERPENS, Hopk., sp. nov. Pl. XXXVII. fig. 3.

Very diffuse and straggling in form; branches robust, transversely striated, bifurcating irregularly at distant intervals; curvilinear in direction, frequently being curved to such an extent that entire branches with all their branchlets are completely bent back upon themselves, gradually lessening in width and bifurcating more frequently from their origin (the hydrorhiza) to their extremities.

This species may be readily distinguished from all others by its serpentine character and straggling form. In its mode of branching, its strong branches, and in their gradual and constantly decreasing width, *Dendrograptus fruticosus*, Hall, is the only form to which it bears any resemblance; and this species is undoubtedly its nearest known ally.

Loc. Lower Llandeilo, Abereiddy Bay (lower zone).

Genus CALLOGRAPTUS, Hall.

CALLOGRAPTUS RADIATUS, Hopk., sp. nov. Pl. XXXVI. figs. 8 *a* & 8 *b*.

Brit. Assoc. Report, 1872.

Flabelliform and wide-spreading, about three inches in length and six in breadth; branches slender, apparently conjoined at their proximal end into a very short and very wide main stem, from which they originate in a dense mass; parallel with each other throughout their length, the radiating almost circular appearance of the polypary being due to their frequent bifurcation; sometimes anastomosing frequently, sometimes proceeding for a considerable distance without being conjoined in any way; more than equal in width to the space between them near their origin, but not quite equal to it near their extremities; hydrothecæ 25 to 30 to the inch, slightly projecting and giving the branches a subarticulated appearance when compressed laterally, and presenting their apertures as minute depressions when the ventral side is uppermost.

The specific name given to this species suffices to distinguish it from every other species of its genus already known, *Callograptus radicans* (which is not nearly so radiating in appearance) being its nearest ally. In one of the specimens figured (fig. 8 *a)* the branches form more than half a complete circle.

Loc. Lower Arenig, Whitesand Bay, and Road Uchaf, Ramsey Island.

CALLOGRAPTUS RADICANS, Hopk.

1872. *Callograptus radicans,* Hopk., Ann. & Mag. Nat. Hist. series 4, vol. x. p. 233, pl. x.

Diffusely flabelliform, attaining a length of fully six inches, and an extreme width of about the same; branches springing from an elongated, erect, and robust main stem which terminates proximally in a spreading fibrous hydrorhiza; bifurcating frequently and continuously throughout their length, at first diverging only slightly, but afterwards at wider angles; anastomosing frequently but at very irregular intervals; hydrothecæ about 20 to the inch, showing only their apertures, which appear as minute oval impressions, the longer diameter of which is parallel with the margins of the branches.

As this species has been so recently described in the 'Annals of Natural History,' we will here only draw attention to its value as showing that the dendroid Graptolites may be inferred to have been similar in their fixed mode of growth to the recent Hydroids of the suborder Thecaphora, its hydrorhiza being an almost exact counterpart of those of many recent sertularian zoophytes.

The plate in the 'Annals' being a reproduction by photolithography of the most perfect specimen of *C. radicans* we have obtained, may be here referred to as showing the condition with regard to preservation, and the general aspect of nearly all the Graptolites of the Lower Arenig rocks of St. David's.

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

CALLOGRAPTUS ELEGANS, Hall. Pl. XXXVI. fig. 9.

1865. *Callograptus elegans,* Hall, Grapt. Quebec Group, p. 134, pl. xix. figs. 1–4 (pl. xviii. fig. 4?).

Broadly flabelliform or semicircular; branches very slender, flexuous, springing from a short flexuous main stem, which terminates proximally in a slight dilatation probably representing the hydrorhiza; bifurcating frequently throughout their length, diverging only slightly from each other and soon becoming almost parallel.

This species differs from all the other known species of its genus in the extreme tenuity of its branches. It is of rather frequent occurrence, associated with two of the species with which it occurs in the Quebec Group (*Callograptus Salteri* and *Tetragraptus serra*). The branches are distinctly striated; but the hydrothecæ cannot be distinguished in any specimens we have found.

The species seems to be nearly allied to *Dendrograptus flexuosus*; and had it not been referred by Hall, from the evidence afforded by the more perfectly preserved examples from the Quebec Group, to the genus *Callograptus*, we should have considered it to be a somewhat anomalous species of *Dendrograptus*.

Loc. Middle Arenig, Whitesand Bay.

CALLOGRAPTUS SALTERI, Hall. Pl. XXXVI. fig. 10.

1865. *Callograptus Salteri*, Hall, Grapt. Quebec Group, p. 135, pl. xix. figs. 5–8.

Narrowly flabelliform, attaining a length of about six inches, and a width of from two to three; branches numerous, undulating, apparently springing directly from the hydrorhiza without the intervention of any common stem; bifurcating at somewhat distant and irregular intervals, diverging very slightly and becoming almost immediately parallel, closely arranged, the space between them being less than their width; occasionally anastomosing.

This species is of frequent occurrence, associated with the preceding, and has a considerable range.

We have specimens more entire and much larger than those figured by Prof. Hall (from two to three times the size), and showing the hydrorhiza, from which the branches appear at once to originate; but none of our specimens are in such a perfect state of preservation as those from the Quebec Group. The hydrothecæ cannot be distinctly made out; but the zig-zag direction of the branches, caused by their alternate disposition, is plainly apparent.

Loc. Middle Arenig, Whitesand Bay.

Genus DICTYOGRAPTUS, Hall.

Dictyonema, Hall, Pal. New York, vol. ii.

When Professor Hall proposed the name *Dictyonema* he was evidently unaware that it was an old-established name for a genus of plants. As this name therefore cannot stand, we feel certain the alteration here proposed will meet with his approval.

Dictyograptus cancellatus, Hopk., sp. nov. Pl. XXXVI. figs. 11*a* & 11*b*.

Brit. Assoc. Report for 1872.

Branches numerous, strong and flexuous, maintaining an equal width throughout; about twelve in the space of an inch, equal in width to one half the interspaces; frequently bifurcating, and anastomosing about as often, and connected occasionally by transverse filaments of the same substance as the branches; fenestrules of a lengthened oval shape, or sometimes approaching a rectangular form, somewhat irregular in proportions and disposition, and about three times as long as wide.

The most distinctive characteristic of this species is that the meshes or interspaces are chiefly formed by the branches coalescing and dividing by virtue of their curvilinear direction, being connected by transverse filaments only here and there where not sufficiently undulated to be brought quite into contact, and not being connected at all where the undulations do not bring the branches into tolerably close proximity to each other.

This form differs so widely from the typical species of *Dictyograptus* that it will most probably ultimately be necessary to make it the type of a distinct subgenus, for which the name *Desmograptus* (*δεσμὸς*, a link) is here proposed.

Loc. Lower Arenig, Whitesand Bay.

Dictyograptus irregularis, Hall. Pl. XXXVI. fig. 12.

1865. *Dictyonema irregularis,* Hall, Grapt. Quebec Group, p. 136, pl. xx. figs. 1, 2.

Branches flexuous, frequently bifurcating, about twenty-five in the space of an inch, equal in width to one half the interspaces; frequently and somewhat regularly anastomosing; the connecting filaments of irregular width (usually slender), expanding at their junction with the branches, and forming very irregularly-shaped fenestrules, usually longer than wide.

It is extremely difficult to draw up a rigid definition of this species, the size and shape of its fenestrules varying so greatly. In our specimens the branches seem to anastomose almost as often as they bifurcate, and the connecting filaments form an irregular, usually diagonal line across the branches, which thus divide and coalesce together—a feature shown in Hall's fig. 1, which is the figure our specimens most nearly resemble in other respects also. The fenestrules seem on the average to be about twice as long as wide, and are most usually of an irregularly oval shape. Very decided indentations, circular in form, are seen here and there on the branches.

Loc. Middle Arenig, Whitesand Bay.

Dictyograptus Homfrayi, Hopk., sp. nov. Pl. XXXVI. fig. 13.

Branches numerous, flexuous, radiating in a complete circle from the centre of attachment, or hydrorhiza; frequently bifurcating, about sixteen in the space of an inch, equal in width to one third the interspaces; anastomosing at frequent but somewhat irregular intervals; the connecting filaments slender, expanding slightly at their junction with the branches, and forming irregularly-shaped fenestrules about twice as long as wide; surface of branches longitudinally striated.

This species seems somewhat nearly allied to the Quebec form *Dictyonema* (*Dictyograptus*) *irregularis*, Hall, but differs from it in its completely circular mode of growth, in its branches being much further apart, and in their being more slender in proportion to the width of the interspaces. Although only small fragments of *D. irregularis* have been found, from the specimens figured by Professor Hall, it could scarcely, in its entire form, have grown in the radiating manner of *D. Homfrayi*, the Quebec species having its branches conjoined at their proximal end into a wide main stem, while in our Ramsey-Island form the branches are scarcely thicker here than at any part of their length, except at their growing extremities.

This species is named after its discoverer, David Homfray, Esq., of Portmadoc.

Loc. Lower Arenig, Road Uchaf, Ramsey Island.

DICTYOGRAPTUS, sp. Pl. XXXVII. fig. 4.

In the Lower Llandeilo rocks of St. David's fragments of a *Dictyograptus* have been found, but they are too imperfect to enable us to determine the species. It has, however, been thought desirable to mention their occurrence, and to figure a specimen, as the genus has not before been recorded as present in the Llandeilo formation.

Loc. Lower Llandeilo, Abereiddy Bay (higher zone).

EXPLANATION OF THE PLATES.

The initials H. H., D. H., J. W. K., and J. H., refer respectively to Mr. Henry Hicks, Mr. David Homfray, Mr. J. W. Kershaw, and Mr. John Hopkinson, from whose collections the species here described are illustrated.

PLATE XXXIII.

Illustrative of the ARENIG RHABDOPHORA *described by Mr. Hopkinson* (*with the exception of* Didymograptus Nicholsoni, *described by Mr. Lapworth.*)

Figs. 1 *a*–1 *d*. *Didymograptus extensus*, Hall, sp. 1 *a*, natural size*; 1 *b*, 1 *c*, 1 *d*, portions of the same, magnified 5 diameters. From Road Uchaf, Ramsey Island: Lower Arenig (*coll. J. H.*).

2 *a*–2 *d*. *Didymograptus sparsus*, Hopk. 2 *a*, natural size; 2 *b*, 2 *c*, portions of the same, magn. 5; 2 *d*, the distal end of a branch, nat. size. From Road Uchaf: Lower Arenig (*coll. J. H.*).

3 *a*–3 *e*. *Didymograptus pennatulus*, Hall, sp. 3 *a*, nat. size; 3 *b*, 3 *c*, portions of the same, magn. 5; 3 *d*, a very young individual, nat. size; 3 *e*, part of a branch of a mature individual, nat. size*. From Road Uchaf: Lower Arenig (*coll. J. H.*).

4 *a*–4 *e*. *Didymograptus patulus*, Hall, sp. 4 *a*, 4 *b*, nat. size. From Porth Hayog, Ramsey Island: Upper Arenig (*coll. H. H.*). 4 *c*, a branch, nat. size*; 4 *d*, 4 *e*, portions of the same, magn. 5. From Llanvirn Quarry: Upper Arenig (*coll. J. H.*).

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* In this figure the artist has made the number of thecæ too small.

5 *a*–5 *d*. *Didymograptus Nicholsoni*, Lapw. 5 *a*, nat. size; 5 *b*, 5 *c*, 5 *d*, portions of the same, magn. 5. From Llanvirn Quarry: Upper Arenig (*coll. J. H.*).

6 *a*–6 *c*. *Didymograptus affinis*, Nich. 6 *a*, nat. size; 6 *b*, part of a branch nat. size; 6 *c*, a portion of the same, magn. 5. From Porth-hayog, Ramsey Island: Upper Arenig (*coll. H. H.*).

7 *a*–7 *c*. *Didymograptus indentus*, Hall, sp. 7 *a*, nat. size; 7 *b*, part of the same, magn. 5; 7 *c*, the distal end of a branch, mag. 5. From Porth-hayog: Upper Arenig (*coll. H. H.*). 7*d*. var. *nanus*, Lapw., nat. size. From Llanvirn Quarry: Upper Arenig.

8 *a*–8 *e*. *Didymograptus bifidus*, Hall, sp. 8 *a*, nat. size; 8 *b*, part of the same, magn. 3; 8 *c*, nat. size; 8 *d*, 8 *e*, young individuals, magn. 5. From Porth Hayog: Upper Arenig (*coll. H. H.*). From Llanvirn Quarry: Upper Arenig (*coll. J. H.*).

9 *a* & 9 *b*. *Tetragraptus quadribrachiatus*, Hall, sp. 9 *a*, a branch, nat. size; 9 *b*, part of the same, magn. 5. From Whitesand Bay (near the slate-quarry): Middle Arenig (*coll. J. H.*).

10. *Tetragraptus serra*, Brongn. sp., nat. size. From Whitesand Bay: Middle Arenig (*coll. J. H.*).

11 *a* & 11 *b*. *Tetragraptus Halli*, Hopk., nat. size. From Whitesand Bay: Middle Arenig (*coll. J. H.*).

12 *a*–12 *d*. *Tetragraptus Hicksii*, Hopk. 12 *a*, 12*b*, nat. size; 12*c*, a branch, nat. size; 12 *d*, part of the same, magn. 5. From Whitesand Bay: Middle Arenig (*coll. H. H. and J. H.*).

PLATE XXXIV.

Illustrative of the ARENIG RHABDOPHORA *described by Mr. Lapworth* (*with th exception of* Clematograptus implicatus *and* Phyllograptus stella, *described by Mr. Hopkinson*).

Fig. 1. *Clematograptus implicatus*, Hopk., natural size. From Whitesand Bay: Middle Arenig (*coll. J. H.*).

2 *a* & 2 *b*. *Nemagraptus capillaris*, Emm. 2 *a*, nat. size; 2 *b*, magnified 4½ diameters. From Llanvirn Quarry: Upper Arenig (*coll. H. H.*).

3 *a* and 3 *b*. *Dicellograptus moffatensis*, Carr., sp. 3*a*, nat. size. 3 *b*. magn. 4½ diam. From Llanvirn Quarry: Upper Arenig (*coll. J. H.*).

4 *a*–4 *f*. *Climacograptus confertus*, Lapw. 4 *a*, 4 *c*, and 4 *e*, nat. size; 4 *b*, 4 *d*, and 4 *f*. magn. 4½. From Porth Hayog, Ramsey Island: Upper Arenig (*coll. D. H. & H. H.*).

5 *a* and 5 *b*. *Diplograptus dentatus*, Brongn. sp From Llanvirn Quarry. Upper Arenig (*col. H. H.*). 5 *c*–5 *k*, specimens illustrating the various appearances presented by the compressed polypary in this species. 5*a*, 5 *c*, 5*e*, 5*g*. and 5*i*, nat. size; 5 *b*, 5 *d*, 5 *f*, 5 *h*, and 5 *k*, magn. 4½. Llanvirn Quarry: Upper Arenig (*coll. J. H.*).

6. *Phyllograptus stella*, Hopk., nat. size. From Road Uchaf, Ramsey Island: Lower Arenig (*coll. J. H.*).

7 *a*–7 *c*. *Glossograptus ciliatus*, Emm. 7 *a*, nat. size; 7 *b*, magn. 4½; 7 *c*, proximal end, magn. 4½. From Llanvirn Quarry: Upper Arenig (*coll. H. H.*).

8 *a*–8 *c*. *Trigonograptus ensiformis*, Hall, sp., nat. size. From Road Uchaf, Ramsey Island: Lower Arenig (*coll. J. H.*).

9 *a*–9 *d*. *Trigonograptus truncatus*, Lapw., nat. size. From Road Uchaf: Lower Arenig (*coll. J. H.*).

PLATE XXXV.

Illustrative of the LLANDEILO RHABDOPHORA *described by Mr. Lapworth.*

Figs. 1 *a*–1 *c*. *Didymograptus euodus*, Lapw. 1 *a*, nat. size; 1 *b*, portion of the same, magn. 4½; 1 *c*. a large branch, nat. size. From Abereiddy Bay: Lower Llandeilo (*coll. H. H.*)

2 *a*–2 *f*. *Didymograptus Murchisoni*, Beck, sp. A selection of examples illustrating the more typical forms of this protean species. From Abereiddy Bay: Lower Llandeilo (*coll. H. H. & J. H.*).

Figs. 3*a*–3*d*. *Didymograptus furcillatus*, Lapw. From Abereiddy Bay: Lower Llandeilo (*coll. J. H.*).

4*a*–4*c*. *Didymograptus indentus*, var. *nanus*, Lapw. From Abereiddy Bay: Lower Llandeilo (*coll. H. H. & J. H.*).

5*a* & 5*b*. *Dicellograptus moffatensis*, Carr., sp., nat. size. From Abereiddy Bay: Middle Llandeilo (*coll. J. H.*).

6*a* & 6*b*. *Diplograptus tricornis*, Carr., nat. size. From Abereiddy Bay: Lower Llandeilo (*coll. H. H.*).

7*a*–7*g*. *Diplograptus foliaceus*, Murch., sp. From Abereiddy Bay: Lower Llandeilo (*coll. H. H. & J. H.*).

8*a*–8*e*. *Climacograptus cœlatus*, Lapw. From Abereiddy Bay: Lower Llandeilo (*coll. J. H.*).

PLATE XXXVI.

Illustrative of the ARENIG CLADOPHORA *described by Mr. Hopkinson.*

Figs. 1*a* & 1*b*. *Ptilograptus Hicksii*, Hopk. 1*a*, natural size; 1*b*, part of the same, magnified 5 diameters. From Road Uchaf, Ramsey Island: Lower Arenig (*coll. H. H.*).

2*a* & 2*b*. *Ptilograptus cristula*, Hopk. 2*a*, nat. size.; 2*b*, part of the same, magn. 5. From Road Uchaf: Lower Arenig (*coll. J. H.*).

3*a*–3*d*. *Dendrograptus flexuosus*, Hall. 3*a*, normal form, nat. size. From Road Uchaf: Lower Arenig (*coll. J. W. K.*). 3*b*, var. *recurvus*, Hopk., nat. size. 3*c*, 3*d*, young individuals, nat. size. From Road Uchaf: Lower Arenig (*coll. J. H.*).

4*a*-4*d*. *Dendrograptus persculptus*, Hopk. 4*a*, nat. size; 4*b*, 4*c*, 4*d*, portions of the same, showing the various appearances presented by the branches, magn. 5. From the creek north of Trwyn-hyrddyn, Whitesand Bay: Lower Arenig (*coll. H. H.*).

5*a* & 5*b*. *Dendrograptus arbuscula*, Hopk. 5*a*, nat. size. From Whitesand Bay: Lower Arenig (*coll. H. H.*). 5*b*, nat. size. From Road Uchaf, Ramsey Island: Lower Arenig (*coll. H. H.*).

6*a* & 6*b*. *Dendrograptus divergens*, Hall. 6*a*, nat. size; 6*b*, part of the same, magn. 5. From Road Uchaf: Lower Arenig (*coll. J, H.*).

7*a* & 7*b*. *Dendrograptus diffusus*, Hall. 7*a*, nat. size; 7*b*, part of the same, magn. 5. From Road Uchaf: Lower Arenig (*coll. J. H.*).

8*a* & 8*b*. *Callograptus radiatus*, Hopk. 8*a*, nat. size. From the creek north of Trwyn-hyrddyn, Whitesand Bay: Lower Arenig (*coll. J. H.*). 8*b*, a young individual, nat. size. From Road Uchaf, Ramsey Island: Lower Arenig (*coll. D. H.*).

9. *Callograptus elegans*, Hall, nat. size. From the slate-quarry, Whitesand Bay: Middle Arenig (*coll. J. H.*).

10. *Callograptus Salteri*, Hall, nat size. From Whitesand Bay (slate-quarry): Middle Arenig (*coll. J. H.*).

11*a* & 11*b*. *Dictyograptus* (*Desmograptus*) *cancellatus*, Hopk. 11*a*. nat. size; 11*b*, part of the same, magn. 5. From the creek north of Trwyn-hyrddyn, Whitesand Bay: Lower Arenig (*coll. J. H.*).

12. *Dictyograptus irregularis*, Hall, nat. size. From Whitesand Bay (near the slate-quarry): Middle Arenig (*coll. J. H.*).

13. *Dictyograptus Homfrayi*, Hopk., nat. size. From Road Uchaf, Ramsey Island: Lower Arenig (*coll. D. H.*).

PLATE XXXVII.

Illustrative of the LLANDEILO CLADOPHORA *described by Mr. Hopkinson.*

Figs. 1*a* & 1*b*. *Ptilograptus acutus*, Hopk. 1*a*, natural size; 1*b*, portions of three branches of the same in their natural position, magnified 5 diameters. From Abereiddy Bay: Lower Llandeilo (*coll. J. H.*).

2*a* & 2*b*. *Dendrograptus Ramsayi*, Hopk. 2*a*, nat. size; 2*b*, part of a branch of the same, magn. 5. From Abereiddy Bay; Lower Llandeilo (*coll. H. H.*).

Fig. 3. *Dendrograptus serpens*, Hopk., nat. size. From Abereiddy Bay: Lower Llandeilo (*coll. H. H.*) Nearly the whole of the shale containing the impression of this specimen is covered with the fine terminal branchlets; but these are only represented in the figure where the actual connexion between them and the main branches is clearly shown.

4. *Dictyograptus*, sp. ind., nat. size. From Abereiddy Bay: Lower Llandeilo (*coll. J. H.*).

Discussion.

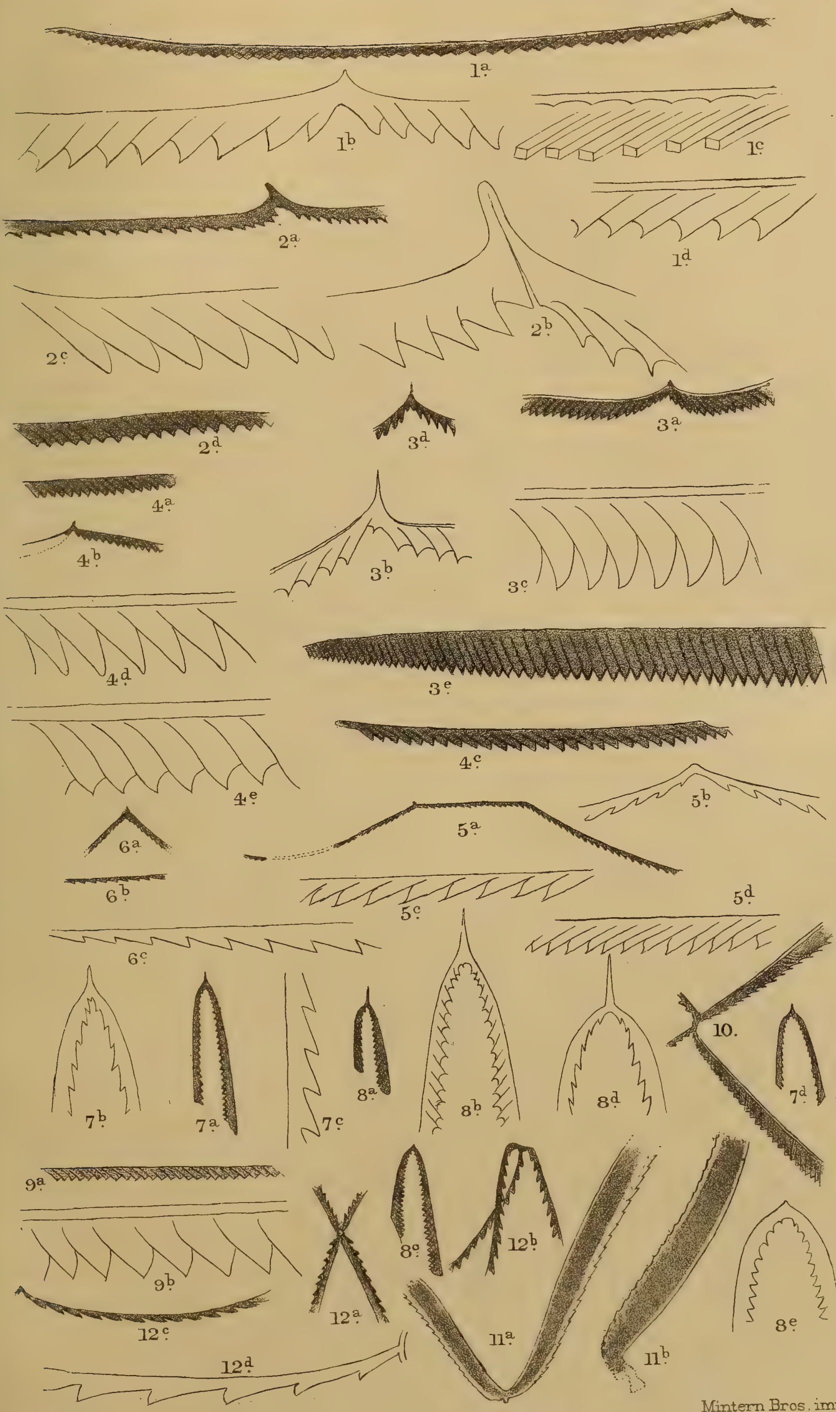
Mr. Carruthers said that this paper added greatly to our knowledge of the Graptolites. He had doubts as to the true position of the Cladophora. Of the Rhabdophora the later forms seemed to be simpler in their structure than the earlier ones.

Mr. Hicks stated that the true Graptolites occur in the lowest part of Ramsey Island, together with the dendroid forms.

Prof. T. Rupert Jones inquired whether, if it were true that the later forms of Graptolites were simpler than the older ones, we may regard this as due to a degeneration leading towards an extinction of the type.

Mr. Hopkinson, in reply, stated that the dendroid forms are only known to occur in abundance, in Britain, in the Arenig rocks of St. David's, and that there are here intermediate forms connecting British and American species, which occur in rocks of more ancient date. He remarked that he did not consider the dendroid forms valuable for determining zones, species very nearly allied to those of the Arenig rocks being met with even in the Lower Ludlow rocks of Shropshire; but the Rhabdophora occur only in small zones, and wherever they are found they seem to hold an equivalent position. They are consequently valuable for stratigraphical purposes. Mr. Hopkinson stated that in recent deep-sea dredgings Hydroids had been found approaching the Graptolites in structure, and that Graptolites have also lately been discovered which have many points in common with the recent Sertularian Zoophytes.

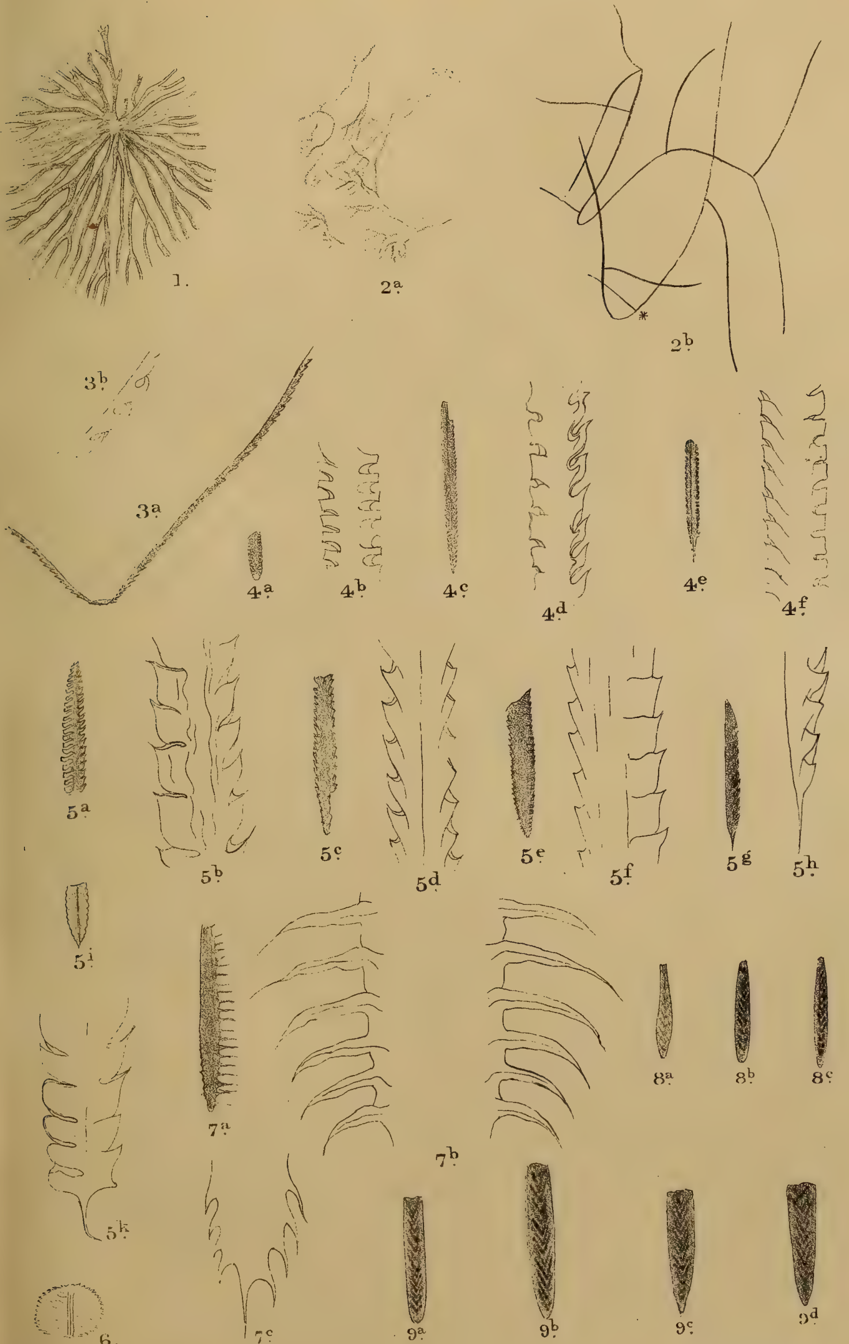
Quart. Journ. Geol. Soc. Vol. XXXI. Pl. XXXIII.



C.H.Ford.

Mintern Bros. imp.

ARENIG RHABDOPHORA.



G. H. Ford.

Mintern Bros. imp.

LLADEILO CLADOPHORA.

G. H. Ford.

Mintern Bros. imp.

LLANDEILO RHABDOPHORA.

G H Ford.

Mintern Bros. imp

ARENIG LADOPHORA

1a.

1b.

2a.

4.

2b.

3.

G.H.Ford.

Mintern Bros. imp.

LLANDEILO CLADOPHORA.

48. *On some* FOSSIL ALCYONARIA *from the* AUSTRALIAN TERTIARY DEPOSITS. By Professor P. MARTIN DUNCAN, M.B., F.R.S., V.-P. Geol. Soc., &c. (Read June 9, 1875.)

[PLATE XXXVIII. A.]

AMONGST the collection of corals which was submitted to me for examination from the Tertiary beds of Cape Otway in Victoria, were some specimens of Isidinæ. My memoir on the Fossil Corals of the Australian Tertiary Deposits, which was published in the Quarterly Journal of the Geological Society, vol. xxvi. 1870, p. 284, did not allude to these Alcyonaria. Now, however, it becomes necessary to examine and describe them; for there are Tertiary beds in New Zealand which contain somewhat similar organic remains (Quart. Journ. Geol. Soc. vol. xxix. p. 375). The Cape-Otway Tertiaries were described in the above-mentioned communication from the writings of Messrs. Daintree and Wilkinson, of the Geological Survey of Victoria; and I ventured to correlate them with particular Tertiary deposits elsewhere in Australia.

Amongst the most interesting of the strata of the Cape-Otway section was that called No. 3, or the Upper Coralline bed. It contained, besides *Amphihelia incrustans* (nobis) and *Balanophyllia Selwyni* (nobis), the specimens about to be noticed. Being the equivalent of the Polyzoan limestone of Wood, which is of Mount-Gambier age, it is a deep-sea deposit, and covers an important series of shallower-water deposits. It is younger than they are, and forms the Upper Miocene of Daintree, the Crag of Wood, and my Upper Cainozoic stage.

The specimens may be divided into three groups, which have a specific significance. In one the Isidian characters are well shown, and the furrows on the calcareous bodies are well developed; in the second the bodies are short, irregular, and deeply furrowed; and in the third they are both long and short, and very slightly furrowed. They are formed of the solid calcareous knots which exist in all Isidinæ, and which in recent forms are connected above and below by a horny tissue, which probably is not preserved by fossilization. The genus *Isis* may be distinguished as follows:—The polyparite has an axis composed of polype-bearing pieces of carbonate of lime, united together by disks of an elastic horny substance. The calcareous bodies form little trunks or columns varying in height and in the amount of external striation. The branches commence from the calcareous bodies, and not from the horny matter.

It is this branching from the calcareous body which distinguishes the genus *Isis* from *Mopsea*, in which the branching starts from the horny substance. Hence, if branching calcareous bodies are found, they may be safely attributed to the first-named genus; but if calcareous bodies without branches present themselves, they may belong to *Mopseæ*, or to parts of species of *Isis* where no branching occurs. Usually, however, the *Mopseæ* have extremely slender polyparites; so that probably all stout and simple calcareous bodies belonging to the Isidinæ should be classified as belonging to the genus *Isis*.

The striation on the surface of the calcareous body consists of ridges and furrows of varying distinctness: they may be almost absent or very deeply marked. It is necessary to remember that this ornamentation is carried onto the upper and under part of the calcareous body, coming more or less to a point there; so that those surfaces greatly resemble worn calices of simple true corals. The furrows are continuous with the water-system of the Alcyonarian, and are the homologues of the striation of the Red Coral (*Corallium rubrum*) as well as of the costal furrows of Madreporaria.

Group 1. Calcareous bodies somewhat constricted, short, branching; ridges distinct and bifurcating; furrows crossed here and there, and moderately deep; colour reddish or yellow. A root of this kind is amongst these specimens. Pl. XXXVIII. A. figs. 5–7.

Group 2. Calcareous bodies very short, elliptical in outline; furrows deep; ridges wide. Pl. XXXVIII. A. fig. 4.

Group 3. Calcareous bodies short, slender, or very short, circular in outline; furrows and ridges rudimentary. Pl. XXXVIII. A. figs. 1–3.

The specimens of the first group are allied to *Isis hippuris* (Ellis & Sol.); those of the second resemble somewhat *Isis corallina* (Morren), a fossil form of the *Calcaire de transition du Groningue* (Milne-Edwards & Jules Haime, Hist. Nat. des Corall. vol. i. p. 196); and the third group of specimens resemble those of *Isis coralloides* (Ed. & H.) of Oceania. It must be understood that these resemblances are of no great value, as they only refer to one portion of the organism, which probably is very variable.

The species of the genus *Isis* live in moderately deep water; but it is evident that specimens may be carried away from their proper location and torn to pieces by the currents, and probably by waves the result of great submarine disturbances. Occurring with *Amphiheliæ* and *Balanophylliæ* and Polyzoa, these specimens indicate a bathymetrical zone of some hundreds of fathoms. All the specimens come from the coralline zone of the Cape-Otway section, or bed No. 3; and they are in the collection of the Geological Society.

EXPLANATION OF PLATE XXXVIII. A.

Australian Fossil Alcyonaria.

Figs. 1, 2, 3 belong to group 3. Fig. 1 (×3), top view; figs. 2 (×4) & 3 (×2), side views of calcareous bodies.

4 belongs to group 2. Top view of calcareous body. Twice nat. size.

5 & 5 *a*. Side and top views of calcareous body belonging to group 1. Twice nat. size.

6. Branching form of calcareous body. Twice nat. size.

7. Basal portion of an Alcyonarian, nat. size. 7 *a*. Portion magnified two diams.

49. *On some* Fossil Alcyonaria *from the* Tertiary Deposits *of* New Zealand. By Professor P. Martin Duncan, M.B., F.R.S., V.-P. Geol. Soc., &c. (Read June 9, 1875.)

[Plate XXXVIII. b.]

Mr. F. W. Hutton, F.G.S., the Curator of the Otago Museum in New Zealand, has forwarded me some specimens from the Awawoa railway-cutting, Oawaru. They are from the upper part of the Oawaru formation, or what Mr. Hutton calls the Trelissic group. He considers the strata to be of that ill-defined age which some geologists term Oligocene, and others Upper Eocene.

The specimens are badly preserved, and consist of fragments of Isidinæ belonging to the genus *Isis*, and of Corallinæ belonging to the genus *Corallium*. There are no true Corals or Sclerodermic Madreporaria in the collection.

The calcareous bodies and some of the bases or roots of the Isidinæ are amongst the collection; and there are many fragments of a slightly branching species of *Corallium*.

Isidinæ.

Genus *Isis*. Plate XXXVIII. b. figs. 1–4.

1. The calcareous bodies are longer than broad, circular in outline, slightly constricted; and the ridges and furrows are distinct. They greatly resemble the specimens described from No. 3 bed, Cape Otway, Victoria, of group 1. (See the last communication.)

2. The calcareous body (fig. 2) is longer than broad, slightly bent; and the ridges are represented by straight series of long low granules; the furrows do not exist. This is quite a new form.

3. A long tapering basal piece (fig. 3), with a base of incrustation. The ridges and furrows are waved and very distinct.

Corallinæ.

Genus *Corallium*.

The specimens are fragmentary.

Some are with frequently branching furrows and ridges of the surface exceedingly developed and irregular in their distribution. They cannot be associated satisfactorily with any recent or fossil species.

These Isidinæ and Corallinæ are dwellers in moderately deep waters; and both of the subfamilies are represented in the recent Pacific fauna. A comparison between the specimens of *Isis* from the Upper Cainozoic of Victoria and of those from New Zealand favours the idea of the homotaxis of the two deposits; but the range in time of the genera prevents the palæontologist from valuing the forms as characteristic. It may be useful to record this discovery, and to compare Alcyonaria from other deposits in the Australian area with them.

EXPLANATION OF PLATE XXXVIII. B.

Fossil Alcyonaria from New Zealand.

Figs. 1 & 1 *a*. Calcareous bodies of group 1 ($\times \frac{3}{2}$).
2. Side view of calcareous body of group 2 ($\times \frac{3}{2}$).
3. Basal portion of an Alcyonarian. Nat. size.
4. Top of a calcareous piece ($\times 3$).

50. *On some* FOSSIL CORALS *from the* TASMANIAN TERTIARY DEPOSITS.

By Professor P. MARTIN DUNCAN, M.B., F.R.S., V.-P. Geol. Soc., &c. (Read June 9, 1875.)

[PLATE XXXVIII. c.]

I HAVE lately received some specimens of fossil corals from the Royal Society of Tasmania, which were collected from the Tertiary deposits of Table Cape, North Tasmania. They are interesting forms; for some of them belong to a new section of the well-known genus *Dendrophyllia*; and one other specimen must be classified with reef-building corals. The geological horizon of the Tertiaries in which the corals were found can fortunately be decided; for they are associated with a very characteristic coral of the group of beds which I have suggested should be classified as Lower Cainozoic, so far as Australia is concerned.

The specimens which I refer to the genus *Dendrophyllia* are very remarkable. They have a fully developed wall-like epitheca, such as is not possessed by any other species, fossil or recent*. In all other respects they are essentially Dendrophyllian in their characters. This very perfect epitheca, acting as it does as a wall or theca, or perfectly or organically merged as it is into the wall, recalls the thin epitheca-like wall of many Palæozoic simple corals.

The genus belongs to the Madreporaria Perforata, and is closely allied to *Balanophyllia*; this last, however, is a simple form, whilst the first branches out. Nevertheless, although many *Balanophylliæ* have an epitheca, it is only slightly visible in a few *Dendrophylliæ*; but its presence in the allied genus renders the association of the new species with the branching forms very reasonable.

The diagnosis of the genus *Dendrophyllia* is as follows:—"Corallum compound, and usually dendroid; corallites more or less cylindrical and produced by gemmation. The calice is subcircular, and the fossa is deep. The columella is more or less well developed; and the septa are thin, close, and unite separately or in groups with their neighbours. The costæ are formed by a series of granules, and are more distinct at the base than elsewhere"†.

It is now proposed to amend this diagnosis by adding—An epitheca may be present, more or less replacing the wall.

DENDROPHYLLIA EPITHECATA, sp. nov. Pl. XXXVIII. c. figs. 1, 2.

The corallum has stout, erect, short, branch-like processes, which do not give out secondary buds. The corallites are slightly curved, subcylindrical, and broader above than below. The epitheca is fully

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* Pourtalès has described two recent *Dendrophylliæ* from the West Indies which have a slight epitheca. Illust. Cat. Mus. Comp. Zool. Harvard, no. iv. p. 45.

† Abstracted and modified from Edwards & Haime, Hist. Nat. des Coralliaires, vol. iii.

developed, and marked with faint transverse ridges and furrows ; it is attached or replaces the wall, and there are no costæ. The septa are in five cycles in six systems. The columella is small in area, but is well developed and papillose. The dissepiments are distant.

Diameter of calice ½ inch.

Locality. Table Cape, Tasmania.

The glazed epitheca, the absence of costæ, and the high septal number distinguish this species from all others. In its habit of growth it resembles *Dendrophyllia cornigera* of the Mediterranean and North Atlantic ; but it only has slight generic affinities with *D. axifuga* of Port Essington in the Australian seas.

The new species has no close allies in any of the Australian Tertiary deposits, and it will serve to characterize the particular beds whence it was taken. It was found associated with large specimens of *Placotrochus deltoideus* (Dunc.), a well-marked coral, which is characteristic of a definite geological horizon in Victoria, South Australia. This fine *Placotrochus* was found over a great area in the Murray Tertiaries, in those of Hamilton, and in the lower (no. 9) beds of the Cape-Otway section*.

These strata are low down in the lowest superficial fossiliferous deposits of the south-eastern part of the Australian area, and rest either on Silurian rocks or on *Tæniopteris* sandstones. They are covered normally by a dense basalt, which is overlain by later fossiliferous deposits—those of the Gambier series ; and these are covered here and there by volcanic ejectamenta. The upper deposits are deep-water ones, and contain Polyzoa in abundance ; but the lower series, the Lower Cainozoic, collected in moderately deep water and in shallow water.

As Northern Tasmania is close to the Tertiary deposits of Victoria, and as both contain the same well-marked coral, which has a very definite vertical range in the last-named district, it is reasonable to correlate the Table-Cape deposits with the new *Dendrophyllia* with the Lower Cainozoics of the mainland.

One specimen of a compound or reef-building coral was found in the Tasmanian deposits. It is part of an incrusting and short Heliastræan. The calices are so worn that they cannot be distinguished ; but the septa and dissepiments are preserved. No such corals were found in the Australian deposits.

EXPLANATION OF PLATE XXXVIII. c.

Fig. 1. Specimen of *Dendrophyllia epithecata.* Nat. size.
2. Half the calice. Twice nat. size.

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* P. M. Duncan, Quart. Journ. Geol. Soc. vol. xxvi. p. 284 ; Wilkinson and Daintree, Geol. Survey of Victoria.

Quart. Journ. Geol. Soc. Vol. XXXI. Pl. XXXVIII.

G.H.Ford.

Mintern Bros. imp.

ALCYONARIA AND CORAL.

51. *On some* Bone-Caves *in* Creswell Crags. By the Rev. J. Magens Mello, M.A., F.G.S. *With an Appendix by* Professor Busk, F.R.S., F.G.S. (Read June 23, 1875.)

On the north-eastern border of Derbyshire a low range of hills, rising from the plateau of the Magnesian limestone, is somewhat abruptly cut through by a short ravine known as Creswell Crags (fig. 1). It is about a third of a mile in length, running nearly east and west, and is bounded on either side by beautifully wooded cliffs, which in places are some 50 or 60 feet high. The limestone is the Lower Permian, and is very hard and massive here, with an easterly dip, which is rather difficult to trace. On either side of the ravine the crags are much fissured, the fissures now and then forming tolerable-sized caverns, opening some 15 feet or less above the level of a sheet of water that has been formed by the damming up of a small stream flowing between the crags from W. to E. Some years ago I had formed a strong wish to examine the fissures in this locality, but until lately could never find the opportunity. Last April, however, I was enabled to pay a preliminary visit to the spot. A very brief inspection sufficed to show me that it was one well worth careful exploration; and in answer to an application to His Grace the Duke of Portland, he very kindly gave me leave to carry on the work.

Fig. 1.—*View of Creswell Crags, looking east.*

On the southern side of the ravine there is a cavern (Fissure C) with a large mouth; but it contracts at a very short distance in, where it has been walled up to keep out foxes, many smaller fissures being similarly protected in the locality. In this cavern, in a small hole I made for testing at the entrance, I obtained, about 3 or 4 inches below the surface, a fine piece of the leg-bone of *Rhinoceros tichorhinus*.

On the northern side of the ravine the fissures are more numerous and extensive. Some shallow openings at the western end have been in use quite lately, as cellars or pig-sties for some cottages recently pulled down; but a little to the east of these there is a fine fissure (A, fig. 2) with a large cavern-like entrance; this fissure, locally called the "Pin-hole," I have begun thoroughly to explore. It penetrates some 40 or 50 yards into the hill-side, running nearly magnetic north, and is fairly horizontal. It is moderately lofty throughout a good part of its course; but a short distance from its entrance it bifurcates and becomes very narrow, the western fork being inaccessible beyond

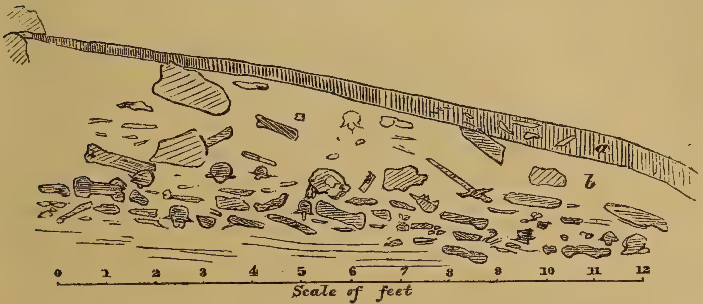
Fig. 2.—*View of Fissure* A *in Creswell Crags, looking north.*

Fig. 3.—*Transverse vertical Section of the Floor of Fissure* A, *in Creswell Crags.*

a. Surface-soil, containing fragments of recent pottery &c., 1½–6 in. thick.
b. Bed of red sand, with rough blocks of magnesian limestone, rolled quartz and other pebbles, and many bones, in great abundance at from 2 to 3 feet depth.

a yard or two; and the other can only be pursued by a sidelong motion, being little over a foot wide. At several points large masses of rock have slipped and are wedged between the roof and the floor; and at other parts the roof is filled up with stalactite. At about 40 yards from the entrance progress is barred by a mass of stalagmite or rock partly closing the fissure, which here gets extremely narrow. A vertical section shows that the fissure inclines at a low angle from west to east from the top downwards. The floor slopes gently upwards and is tolerably smooth, especially near the mouth. With the kind and able assistence of a non-geological friend, Mr. C. White, of Chesterfield, I began a thorough examination of the contents of the floor of this fissure; the result of this, as far as it has been at present carried out, I will now proceed to give.

Fig. 4.—*Longitudinal Section of the Floor at the Entrance of Fissure* A, *in Creswell Crags.*



For letters see fig. 3.

The cutting was commenced near to the entrance of the cave; and after three days' work the following section was obtained (see figs. 3 and 4):—

1. Surface-soil, containing recent pottery, bones, &c. .... 1–6 in.
2. Damp red sand, with rough blocks of magnesian limestone, quartz, quartzite and other pebbles, and numerous bones .... 3 feet.
3. Lighter-coloured sand, consolidated by infiltration of lime. No bones yet found .... (?)

The layer of surface-soil is some 6 inches thick or more at the entrance, but gets very thin further in, until a point is reached about 23 feet from the beginning of the cutting, where two large projections of rock contract part of the fissure. Behind these this layer is considerably thicker, and about 4 inches below the surface it contained a fine flint flake. All the other contents of this layer hitherto found are quite recent, being mere fragments of brown and white earthenware, bits of pipes, &c. The underlying bed of red sand proved to be very rich in bones; this I have carefully removed throughout a space 25 feet long by about 2 feet wide (being the full width of the fissure), and to its entire depth, viz. about 3 feet. There were no traces of regular bedding in this sand; only here and there its character was modified by the decomposition of some of the limestone blocks. From the surface downwards bones were found in great abundance in all parts of this bed; but they were specially massed together at the bottom of it. The bones were much broken, and many of them very evidently gnawed by Hyænas, of which animals numerous teeth and fragments of the lower jaws were found. Many of the longer bones lay with their long axes parallel to the sides of the fissure, and with their heavier ends foremost. Other bones were wedged together close to the sides in masses consisting of vertebræ, parts of leg-bones, and of antlers. The bones are in various stages of preservation, some being very decomposed and fragile, others very fresh-looking, although lying side by side with them; in all probability there has been a certain amount of rearrangement of the bones at an early period by the flow of water through the fissure, which appears to have been at one time a hyæna-den. One large fragment of mammoth's bone partly extended from the sand bed into the surface-soil; and at some distance in, a fine molar of the same animal was found, about 1 foot below the top of the bed. Several very perfect molars of *Rhinoceros tichorhinus* and portions of antlers of deer were obtained at this point, together with some of the hyæna-jaws already mentioned; two large fragments of the leg-bones of the rhinoceros and a number of smaller leg-bones lay not very far apart near the same spot, where a huge block of limestone had apparently caused an obstruction. Where the fissure was contracted by projecting portions of rock which were partly undermined, the sand was of a very calcareous nature, being full of angular pieces of the limestone, many of which were of a soft and crumbly nature. There were not so many bones here, the few found being very fragmentary and friable; and at present very few bones have been met with at the back of the barrier. This is a thing difficult to understand upon the hypothesis of the bones having been carried into the fissure from the back, which was the opinion I had first formed, basing it upon the parallelism of the larger bones to the sides of the fissure. Professor Busk has very kindly examined and named the numerous bones found in this fissure (A), the list of which is appended to this paper.

Besides the remains of larger animals, great quantities of teeth and other bones of small rodents (*Arvicola* &c.) were disseminated throughout the sand, which also contained some cycloid fish-scales, and a few vertebræ of some fish.

The sand bed No. 3, on which the bone-bearing bed rests, is sharply defined from it, being much lighter in colour; it is highly calcareous and is consolidated into semiconcretionary-looking masses below the rocky barrier already alluded to. At this point I cut into it to a depth of 1 foot without finding any trace of the bones which were so abundant immediately above it. At present I have not been able to ascertain its thickness, and I have nowhere reached the bottom of the fissure.

Some hundred yards or so lower down the ravine a large cavern, "Robin Hood's Cave" (cavern B), is met with, containing four or five large chambers, which have very evidently been used for human occupation. A superficial cutting showed the surface-soil to be not much above an inch thick at the entrance, and that it rested on a similar sand to that found in the first fissure; in this surface-layer were several lower molars of *Rhinoceros tichorhinus* and some hyæna-teeth, some of which were also found in the top of the underlying sand bed, together with numerous chippings of flint, a bit of a flint flake, and also some implements made from the pebbles so frequent in this sand.

There is no flint found in the neighbourhood; so, doubtless, our ancestors would be glad to made use of the best material they could obtain on the spot, viz. pebbles derived, together with the sand itself, I should suppose, from the denudation of the once overlying Bunter beds.

The upper part of the floor of this cavern also contained a small piece of Samian ware showing an ornamental rim, and with this two or three pieces of a coarser earthenware vessel; a few recent bones of sheep and a human tooth were also found here. The exploration of this cavern I hope to be able to pursue as soon as that of the one already successfully begun has been completed.

List of the Animals whose remains were found in the First Fissure (A), Creswell Crags.

Homo.
Ursus, sp. ?
Gulo luscus.
Canis vulpes.
—— lupus.
—— lagopus.
Hyæna spelæa.
Cervus megaceros.
—— tarandus.
Ovis.
Bos primigenius.
Equus caballus.
Rhinoceros tichorhinus.
Elephas primigenius.
—— antiquus ?
Lepus timidus.
Arvicola.
A bird, sp. ?
Fish, sp. ?

APPENDIX.

List *of the* Mammalian Remains *collected by the* Rev. J. M. Mello *in the Rock-Fissure Cavern in Creswell Crags, Derbyshire.*

By Professor G. Busk, F.R.S., F.G.S.

The bones forming this collection belong to species of the genera:

1. *Ursus.*
2. *Hyæna.*
3. *Canis.*
4. *Gulo.*
5. *Bos.*
6. *Cervus.*
7. *Ovis.*
8. *Equus.*
9. *Rhinoceros.*
10. *Elephas.*
11. *Arvicola.*
12. *Lepus.*

I. Order CARNIVORA.

1. Ursus.

The principal remains belonging to the Bear are:—

1. A sixth cervical vertebra, the body of which measures 2·4 inches in transverse diameter.

2. Several other vertebræ, dorsal and lumbar.

3. A perfect scapholunare of the right side, measuring 2·1 × 2·2 inches in antero-posterior and transverse diameters.

4. A third lower molar, much worn, and dark-coloured, measuring 0·9 × 0·7 inches.

5. A scaphoid of smaller size.

The dimensions of these bones and tooth, with the exception of the navicular last enumerated, would indicate that they belonged to an animal of large size; and from the dimensions of the tooth I should be inclined to refer it to *Ursus ferox*. None of them presents any characters rendering it likely that the species was *U. spelæus*.

2. HYÆNA.

H. spelæa is represented by portions of several lower jaws, teeth, and other bones, which call for no particular remark, except that they all appear to have belonged to aged individuals—several of the teeth being worn to mere stumps.

3. CANIS.

Three species of the genus *Canis* are represented in the collection.

1. C. LUPUS.

Numerous bones of a large Wolf occur, amongst which the principal are:—

1. A portion of the mandible containing the $\overline{\text{pm. 4}}$ and $\overline{\text{m. 1.}}$ The specimen is chiefly remarkable for the extreme wearing of the teeth.

The dimensions of the teeth, as regards length and thickness, are precisely the same as in a specimen of the Arctic Wolf (No. 4370 A, R. C. S.) with which I have compared them. At the same time, however, it should be remarked that the dimensions of $\overline{\text{m. 1}}$, or the lower carnassial, are exactly alike in the European and Arctic Wolf, whilst the length of the fourth premolar is rather greater in the European form. In the size of the latter tooth the cave-specimen agrees exactly with *Canis occidentalis*; and to that extent the fossilized specimen may be regarded as more nearly approaching the American than the existing European species.

I would also here remark that in a specimen of Wolf from the Cavern of Gailenreuth, the difference in the size of all the premolars, except the first, is in the same direction; that is to say, so far as I have had an opportunity of observing, it would seem not improbable that the existing European Wolf has rather larger premolars than the ancient cave-animals. The point is perhaps one worthy of more extended inquiry.

2. A perfect atlas, the transverse diameter of which is 4·15 inches. The muscular impressions are very strongly marked.

3. A nearly perfect axis, which accords with the above exactly in size, and might be supposed, as I think is highly probable, to belong to the same individual; the two, however, differ in colour.

The extreme length of this vertebra, measured from the summit of the odontoid process, is 2·35 inches, and its transverse diameter, at the anterior articular facets, 1·5 inch. Both these bones are rather larger than the corresponding vertebræ of the common Wolf, with which I have compared them; but otherwise they present no distinctive characters.

4. Several other vertebræ, including an entire fifth cervical, a broken dorsal, &c.

5. The greater part of the left humerus, wanting the proximal end.

6. The proximal half, or nearly so, of the right ulna, corresponding in size.

7. The proximal end of the left ulna, of smaller size.

8. A large portion of the left tibia, of which the proximal epiphysis is detached; but notwithstanding the immaturity of the bone, the shaft is fully as large as that of the common Wolf.

9. Two left third metacarpals, one measuring 3·4 inches and the other 3 inches in length.

10. A fourth metacarpal, 2·9 inches long.

11. Two right fourth metatarsals, one measuring 3·4, and the other 3·2 inches.

12. Two fragments of ribs, including the head and angle—one larger than the other.

13. A fragment of the pelvis, showing part of the acetabulum.

14. Various teeth, and other more or less fragmentary bones.

From the above it would appear that the collection includes the remains of at least two individual Wolves, one of larger size than the other, and showing, in size and in some other respects at present indecisive, characters not unlike those of *C. occidentalis*.

2. C. VULPES.

The common Fox, or one corresponding with it in size, is represented by several bones, amongst which may be specified:—

1. An almost complete left os innominatum with the acetabulum entire, and with about half the foramen ovale remaining. The acetabulum has a diameter of 0·5 inch, and the latter a longitudinal diameter of about 0·8 inch.

2. A small fragment of the right os innominatum, differing from the preceding in colour and thickness.

3. An almost entire humerus of an immature animal, wanting the proximal epiphysis.

4. Several canines and other teeth, &c., all in character corresponding with those of the common Fox.

3. C. LAGOPUS.

The presence of the Arctic Fox depends unfortunately only upon the evidence of a single, or perhaps of two specimens.

That upon which I rely in the diagnosis is a nearly entire axis vertebra. This single bone, however, which is nearly black in colour (in that respect corresponding with the larger Wolf), appears to me to be amply sufficient to identify the species to which it belonged. In order to render the distinction more immediately evident between this specimen and the corresponding vertebra of the common English Fox, and at the same time to show how exactly it resembles the same bone in the Arctic Fox, I have subjoined figures of the three bones, in which it will be seen that, besides their considerable difference in size from the larger, the two smaller vertebræ correspond with each other in all other respects.

Figs. 1–3.—*Second Cervical Vertebra of the Arctic Fox, recent and fossil, and of the Common Fox.*

Fig. 1.—*Arctic Fox.* Fig. 2.—*Fossil Specimen.*

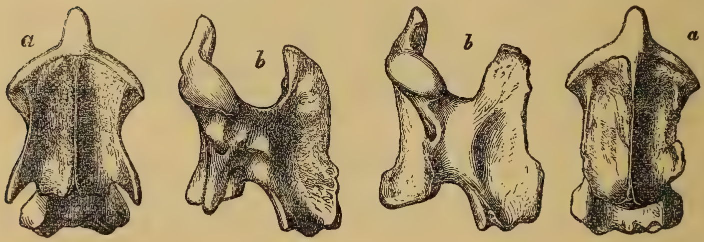
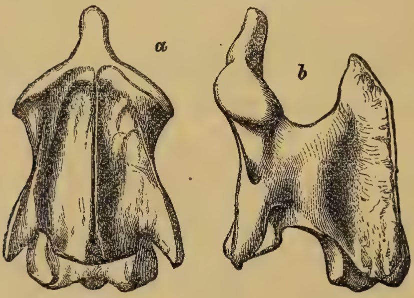


Fig 3.—*Common Fox.*



a. Lower surface. *b.* Side view.

The chief points of difference between the axis vertebra of the Arctic and of the common Fox may be briefly stated to consist in :—

(*a*) The smaller size of the former *.

(*b*) The slenderness and more abrupt divergence of the transverse processes.

(*c*) The much greater prominence of the median keel or carina on the under surface of the centrum.

(*d*) A difference, difficult to describe, but sufficiently obvious on comparison, in the form of the anterior articular facets.

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* The specimen of common Fox taken for comparison is of small size, and it forms part of the skeleton of a Fox killed in Warwickshire, in the College Museum.

As, unfortunately, the slender transverse processes are both broken off in the cave-specimen, their size can only be estimated from the fractured surface, close to which the vertebrarterial foramen or short canal may be seen, which appears to be of very small size, as in the Arctic compared with the common Fox.

The greater prominence of the keel in the Arctic Fox is seen both in the front view and, still better, in the lateral view of the axis of both the Arctic and Cave-Fox (figs. 1 & 2) as compared with the same point in fig. 3. In both the small vertebræ the keel will be seen (in the side view, *b*) to project slightly beyond the level of the lateral alæ of the centrum, by which, in the common Fox it is concealed when the bone is viewed in the same position.

Having compared several specimens of the Arctic Fox, it appears to me that the differences above noted are constant; and I have therefore little or no hesitation in referring the axis from Creswell Crags to *Canis lagopus*, thus adding that species, so far as I am aware, for the first time to the British antral fauna.

The association, moreover, of this species with the Reindeer, Glutton, and Elk cannot be regarded as at all improbable *.

4. GULO LUSCUS.

Not more than two well-marked remains of the Glutton have been noticed by me in the collection. One of these, which is represented in the accompanying woodcut (fig. 4), is a fragment of the pelvis, presenting the acetabulum and portions of the foramen ovale and of the greater sciatic notch. The distinctive characters of the bone nevertheless seem to be fully shown in this fragment. The only species of mammal whose pelvis in the corresponding part could be confounded with the present specimen is the common Badger (*Meles taxus*); but the difference between the two, even in such an imperfect relic, is sufficiently marked. In *Gulo* the foramen ovale is more elongated than in the Badger, in which it is nearly circular; and this greater length is well shown in the specimen figured.

Again, the edge of the ischial border of the greater sciatic notch is more abruptly curved inwards at the upper part, as at *b* in the figure, in *Gulo* than in *Meles*.

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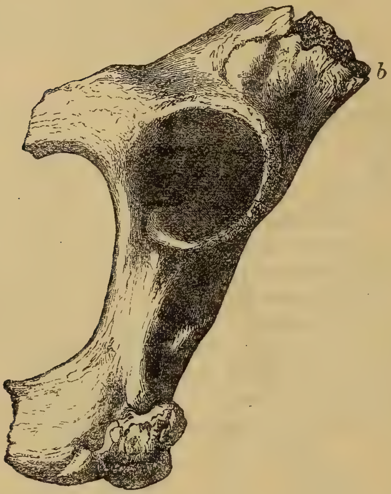
* In a recent number of the Archiv. f. Anthropologie (vol. viii. p. 123 *et seq.*) is an account by M. Rütimeyer of the animal remains discovered in a cavern at Thayingen, near Schaffhausen. Amongst these he describes the remains of two species of Fox differing from the common European *C. vulpes*. One, of which not less than 60 lower jaws were met with and a good many upper ones, resembled in its dentition *C.* (*Vulpes*) *fulvus* of America. Of the second species, which M. Rütimeyer terms *C. lagopus*, about 90 mandibles besides other bones were found, whilst the animal itself was very graphically represented in an incised engraving on a bone of Reindeer, showing that without doubt this Arctic species was at that period abundant in Middle Europe and familiarly known to the men of the Reindeer Period in Switzerland. It is interesting also to remark that M. Rütimeyer enumerates in the fauna of Thayingen five individuals at least of the Glutton, and that, although no actual relics of the Musk-Ox were discovered, certain evidence of its existence in the neighbourhood at the same period was afforded by a very characteristic carving of the head in bone.

Fig. 4.—*Pelvis of* Gulo luscus.



The second fragment, also of the pelvis, though less perfect, presents the same characters, so far as they can be perceived.

II. Order RUMINANTIA.

1. Bos.

Bones of a large Bovine species constitute the greater bulk of the Collection. All (with one or two exceptions of smaller size) are of the same type; and most of them, in all probability, belong to the same individual.

Amongst these may be enumerated :—

1. An atlas, recently broken into several fragments. The condyloid cup measures 4·7 by 10·0 inches, and the axial articulation 5·3 inches in transverse diameter. The transverse diameter of the ring at the hinder border is 2·5 inches.
2. An axis 4·0 inches long, with a least diameter of the centrum of 3·5 inches.
3. All the remaining cervical vertebræ.
4. Several dorsal and lumbar vertebræ. (Altogether between 35 and 40 vertebræ).
5. A left radius measuring 14 inches in length.
6. The corresponding humerus, 13·5 inches long, with a least circumference of 7·75 inches.
7. A left metatarsal.
8. Left femur wanting the distal extremity.
9. The corresponding right femur, comprising the entire shaft.

10. Left tibia, including the distal articular extremity, which fits one of the astragali.
11. Several astragali, right and left.
12. A left calcaneum fitting the astragalus which accords with the tibia.
13. Several right calcanea, one pairing with the above.
14. A perfect os lunare, dark-coloured and heavy, in which respect it differs from most of the other bovine bones.
15. A right cuboid, in the same condition.
16. Distal extremity of a metacarpal.
17. An entire metacarpal with
18. An os magnum, and
19. Four corresponding phalanges.
20. About 12 more phalanges of the same size and character.

The dimensions and general character of these bones are such as to leave no doubt of their belonging to *Bos primigenius*.

2. CERVUS.

1. C. TARANDUS.

Numerous bones of the Reindeer, some quite entire, together with portions of the skull with the bases of the horns remaining, and several portions of antlers, show that that species was abundant in the fauna of the Cave-period in that district. These remains call for no special remark beyond this, that they are generally of rather small size. A perfect metacarpal, for instance, measures 7·4 inches in length, the proximal end being about 1·4 inch in transverse diameter, and the distal 1·7. The various sizes, however, of the acetabulum in different specimens render it evident that there was considerable individual variation in stature.

2. C. MEGACEROS.

The Irish Elk is represented by:—

1. A perfect metacarpal measuring 14·8 inches in length. It is evidently that of an old animal; and the bone is morbidly enlarged at the distal end above the articular epiphysis.
2. The lower two thirds of the left tibia, old and gnawed, which fits
3. An astragalus, to which again fits
4. A perfect calcaneum.
5. A corresponding scapho-cuboid.

All these appear to belong to one individual; but besides them there are:—

6. Three or four other astragali, right and left, two of which are much gnawed, but the others quite perfect.
7. Several phalanges.
8. Portions of a right and left femur, probably pairing with each other.
9. A splintered fragment of a metatarsal, probably split by Hyæna.
10. A much worn and very old upper molar.

There is nothing remarkable in these bones. They indicate the presence of several individuals, one of which at least, to judge from an astragalus, must have been of small size as compared with the average Irish Elk; whilst amongst the others must have been one of large stature, as estimated from a metacarpal nearly 15 inches long, the usual length of that bone in the fossil Elk being under 14 inches.

3. Ovis.

1. O. ARIES.

A lower jaw. and a detached ulna represent the Sheep amongst the collection; but both appear to be quite recent.

III. Order PERISSODACTYLA.

1. Equus.

1. E. CABALLUS.

The principal remains of the Horse belong to an animal of medium size. Those of most importance are:—

1. The lower half of a tibia, gnawed apparently by a Wolf.
2. The distal end of a cannon bone.
3. Several teeth of both upper and lower jaw, in no way distinguishable from those of the existing Horse.

2. Rhinoceros.

All the remains of Rhinoceros in the collection appear to belong to *R. tichorhinus*; amongst them may be noted:—

1 and 2. The middle portions of the shaft of the right and left humerus, obviously of the same individual. They are both gnawed by Hyæna in the same way in which that carnivore almost invariably attacks the bone in question. The whole of the proximal extremity and the upper part of the shaft are gone, together with the outer condyle and corresponding part of the shaft.

3. Several upper and lower molars, all presenting well marked tichorhine characters.

4. Four astragali—three more or less gnawed, and one quite entire, which fits into

5. The distal portion of a right tibia.

6. A fragment of the scapula.

7. A portion of the shaft of the left tibia, but apparently not of the same individual as the right tibia above noted.

8. A fragment of the right calcaneum.

9. An entire and perfect third metacarpal.

10. Several fragments of ribs &c.

Mr. Mello is disposed to assign a lower molar of *Rhinoceros*, in his possession, rather to *R. hemitœchus* than to *R. tichorhinus*. The tooth, however, is so much worn that its determination must be very doubtful. Of the other Rhinocerine remains that have come under my observation there can be no doubt whatever.

IV. Order PROBOSCIDEA.

1. Elephas.

1. Elephas primigenius.

1. This species is clearly indicated by a nearly entire upper molar, having a transverse diameter of 1·25 inch and containing four plates in a length of 1·2 inch = 0·3 for each plate. The characters are clearly those of the Mammoth.

2. A large fragment of a long bone, most probably elephantine, and some smaller and more doubtful pieces.

3. Besides the above remains of Elephant, Mr. Mello has a second, small molar tooth which I have not had an opportunity of examining, but which, from a photographic figure, would appear to exhibit the character of *E. antiquus*, from the thickness and smaller number (8–9) of the plates.

Discussion.

Prof. Busk made some observations on the Mammalian remains exhibited by Mr. Mello. These are embodied in the preceding Appendix.

Dr. Ogier Ward mentioned the occurrence of similar bones in well-sinking at Eastbourne.

Mr. Evans remarked that we have in these fissures bones extending from Roman times far back, and expressed a hope that Mr. Mello would be able to distinguish those belonging to different periods. The general facies of the flint implements was neolithic.

Mr. Mello stated that the implements were all found near the surface.

52. *On some* IMPORTANT FACTS *connected with the* BOULDERS *and* DRIFTS *of the* EDEN VALLEY, *and their Bearing on the Theory of a Melting Ice-sheet charged throughout with Rock-fragments.*

By D. MACKINTOSH, Esq., F.G.S. (Read June 23, 1875.)

[Abstract.]

IN this paper the main object of the author was to defend generally received opinions, especially as regards the great glacial submergence, in opposition to the theory announced in the Quart. Journ. Geol. Soc. for last February (vol. xxxi. p. 55). He brought forward a number of facts and considerations founded on repeated observations* which extended over part of the Lake-district and neighbouring plains, not apparently examined by Mr. Goodchild, though included in his theory. He stated that he had not found it safe to rely on a comparison of hand-specimens (as Mr. Goodchild has partly done), but that boulders, especially of granite, syenite, and felspathic rocks, require to be traced back to their sources. He maintained that the dispersion of Criffell granite boulders is so interwoven with that of boulders of porphyry and syenite from the mountains of the Lake-district as to be incompatible with the theory of transportation by currents of land-ice, and that the limitation of Criffell boulders along the north and west borders of the Lake-district mountains to a few hundred feet above the present sea-level is inconsistent with the idea of a boulder-charged ice-current 2400 feet in thickness. He likewise called attention to the interweaving of Criffell with Shapfell granite in the lower part of the Eden valley, as being inexplicable by upper and under currents of land-ice. He remarked that Mr. Goodchild has not directly referred to the dispersion of numerous boulders of Shapfell granite over ground at least 1300 feet above the sea, as far south as Milnethorpe. He defended the idea of a special, though not abruptly commencing, dispersion of surface-blocks of Shapfell granite (contrary to his first impressions), and thought that the limited altitude (1500 feet ?) they have reached on Stainmoor is opposed to the theory of an ice-current "charged *throughout* with rock-fragments of all sizes" and attaining a thickness of 2300 feet; while an ice-current only 1500 feet in thickness (above the present sea-level) on Stainmoor, could not have spread out like a fan, and carried boulders as far as Royston, the coast of Holderness, Sedgefield near Durham, and over the East-Moorland hills. The author believes that some of Mr. Goodchild's sections are abnormal, while others which exhibit very complicated phenomena are paralleled in the maritime drifts in the plains of Cumberland, Lancashire, and Cheshire. The eskers of the Eden valley are similar in structure to those which contain sea-shells on the Welsh borders and elsewhere.

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* For detailed accounts of these observations see Geol. Mag. for October and December, 1870, and June and July 1871. See also Quart. Journ. Geol. Sec. for August 1873.

They generally show traces of having been *piled up* rather than *thrown down*, as Mr. Goodchild supposes. The author denied that the sea cannot throw down clays at angles of from 15° to 30°, and stated his grounds for believing (with the Rev. M. H. Close) that the sudden disappearance of the ice-sheet can be better explained by the encroachment of the sea than by the sudden melting of the ice. But the author's main argument against Mr. Goodchild's theory was derived from the *purity* of the interiors of existing ice-sheets, as shown by Professor Wyville Thomson and other eminent authorities.